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Molecular phylogeny and morphology reveal four new species in Hymenochaetales and one new species in Cantharellales from Southwestern China

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Abstract

Wood-decaying fungi represent a vital group of higher fungi that drive the cycling of matter and energy in forest ecosystems, and they have been the focus of thorough investigation. In this study, five new species, *viz*. *Botryobasidium daweishanense*, *Inonotus subglobisporum*, *Kneiffiella bubalina*, *Xylodon granulanoides*, and *X. granulans* from China, are described and illustrated based on the morphological characteristics and molecular phylogenetic analyses, in which the sequences of ITS+nLSU genes were used for the phylogenetic analyses by maximum likelihood and Bayesian inference methods. The phylogeny revealed that the *Botryobasidium daweishanense* groups with three taxa, *viz*., *B. intertextum*, *B. leptocystidiatum*, and *B. subcoronatum*. *Inonotus subglobisporum* is closely related to *I. radiatus*. *Kneiffiella bubalina* clustered sister to *K. subalutacea*. *Xylodon granulanoides* and *X. granulans* have a close relationship with *X. bambusinus*, *X. fissuratus*, *X. subclavatus*, *X. montanus*, and *X. wenshanensis*. Additionally, *Xylodon granulanoides* and *X. granulans* clustered together. *Botryobasidium daweishanense* is characterized by an araneose hymenial surface, fusiform, and cyanophilous basidiospores (6.1–7.3 × 3.3–3.9 µm). *Inonotus subglobisporum* is characterized by perennial basidiomata with lateral stipes, polygon pores measuring 4–6 per mm, and subglobose, cyanophilous basidiospores (3.6–4.3 × 2.8–3.5 µm). *Kneiffiella bubalina* is characterized by cream basidiomata and cylindrical to slightly allantoid basidiospores (8.0–8.9 × 1.8–2.3 µm). *Xylodon granulanoides* is characterized by grandinioid hymenial surfaces, various cystidia, and broadly ellipsoid, thick-walled basidiospores (4.7–5.3 × 3.6–4.1 µm). *Xylodon granulans* is characterized by grandinioid hymenial surfaces, capitate and clavate cystidia, and broadly ellipsoid basidiospores (3.8–4.2 × 2.9–3.3 µm). Phylogenetic analysis based on internal transcribed spacer (ITS) and nuclear large subunit RNA (nLSU) shows that the four species are members of Hymenochaetales, and one belongs to Cantharellales. All five new species are compared with morphologically and phylogenetically closely related species. The present study contributes to understanding the species diversity, taxonomy, and phylogeny of macrofungi in Southwestern China.

Key words: Biodiversity, Cantharellales, Hymenochaetales, new taxa, wood-inhabiting fungi

* These authors contributed equally to this work and share the first authorship.

Introduction

Wood-inhabiting fungi thrive on various types of wood, including vigorous wood, dead wood, and fallen branches. They play a crucial role in degrading the lignin, cellulose, or hemicellulose present in wood, making them an important group of higher fungi (M'Barek et al. 2020; Runnel et al. 2021; Dong et al. 2023, 2024a). These fungi are the cornerstones of matter cycles and energy flows in forest ecosystems and play a vital ecological role in the regulation of carbon storage (Phookamsak et al. 2019; Ponce et al. 2023). A robust understanding of wood-fungi diversity is required to explain their rise to forest dominance; however, the classification of some taxa remains unknown.

The genus *Botryobasidium* Donk belongs to the family Botryobasidiaceae Jülich (Cantharellales, Basidiomycota) and is typified by *Botryobasidium subcoronatum* (Höhn. & Litsch.) Donk. Species of the corticioid *Botryobasidium* are saprobic fungi that cause white rot in forested areas (Langer et al. 2000b; Bondartseva and Zmitrovich 2023). They are commonly found on a range of hosts or substrates, from litter and fallen trunks to the stems of living trees, including macrophanerophytes (Langer et al. 2000a, 2000b; Hjortstam et al. 2005; Zhou et al. 2024a). Fungi in this genus have resupinate, smooth to grandinioid basidiomata; branched right-angled hyphae with or without clamp connections; short, cylindrical or subcylindrical to suburniform basidia with 2–8 sterigmata generally arranged in clusters; and narrow to globose, smooth to tuberculate or laciniate, and inamyloid basidiospores (Langer et al. 2000a; Bernicchia et al. 2010). According to the Index Fungorum (www.indexfungorum.org; accessed on 26 January 2025), the genus *Botryobasidium* has 116 specific registered names, with 101 species accepted worldwide (Dong et al. 2024b; Liu et al. 2024; Zhou et al. 2024a; Zhou et al. 2024b). Based on ITS data analysis, we demonstrated that the genus *Botryobasidium* formed a well-supported monophyletic group, as previously demonstrated by its micromorphological and ultrastructural characteristics (Langer and Langer 1998; Moncalvo et al. 2006; Zhou et al. 2024b).

Frey et al. (1977) established the order Hymenochaetales Oberw., using Hymenochaetaceae Donk as the type family (He et al. 2024). Hymenochaetales is a large order of Agaricomycetes with 14 families, 83 genera, and 1205 species, including wood-inhabiting and ectomycorrhizal fungi. These fungi have different kinds of basidiomata, such as polyporoid, stereoid, corticioid, hydnoid, coralloid, and agaricoid (Hibbett et al. 2014; He et al. 2024). Hymenochaetaceae includes species with brownish basidiomata and generative hyphae without clamp connections. This family includes six genera, namely, *Coltricia* Gray, *Cyclomyces* Kunze ex Fr., *Hydnochaete* Bres., *Hymenochaete* Lév., *Inonotus* P. Karst, and *Phellinus* Quél, laying the foundational framework for the classification of Hymenochaetaceae (Hibbett et al. 2014; Wijayawardene et al. 2022; He et al. 2024). However, the phylogeny of *Hymenochaete* is not well understood, and researchers have investigated the phylogenetic relationships of these genera (Wagner and Fischer 2002). Phylogenetic analyses of *Hymenochaete* and its allied genera have been performed, and the results have been verified by mycologists (Larsson et al. 2006; Dai 2010). Furthermore, a series of studies indicated that certain species have a high degree of host specificity (Dai 2010; Purahong et al. 2018; Wang et al. 2021, 2022; Wu et

al. 2022; Zhao et al. 2023a; Zhou et al. 2023). The diversity of *Hymenochaete* fungi and the number of species recorded in China have also been extensively studied (Korotkin et al. 2018; Wu et al. 2022; Zhao et al. 2023a, 2024).

Inonotus, one of the largest genera within the Hymenochaetaceae family, is typified by *Inonotus hispidus* (Bull.) P. Karst; it is primarily found as parasites or saprophytes on various types of wood (Wagner and Fischer 2002; Zhou et al. 2015). Fungi of this genus have annual to perennial, resupinate, effused reflexed or pileate, yellowish to brown, hispid, velutinate to rough or glabrous pilei; a brown pore surface; homogeneous, brown, corky context basidiomata; a monomitic hyphal system; and generative hyphae with simple septa. Hymenial setae may be present or absent; hyphoid setae are found in some species and are ellipsoid, hyaline to brownish, thick-walled basidiospores. Previous phylogenetic analyses indicated that *Inonotus sensu lato* had polyphyletic origins, and four more narrowly defined genera, namely *Inocutis* Fiasson & Niemelä, *Inonotopsis* Parmasto, *Mensularia* Lázaro Ibiza, and *Onnia* P. Karst., were segregated from *Inonotus* (Wagner and Fischer 2002; Dai 2010). Meanwhile, two new genera were proposed (Zhou et al. 2016): *Sanghuangporus* Sheng H. Wu, L.W. Zhou & Y.C. Dai, and *Tropicoporus* L.W. Zhou, Y.C. Dai & Sheng H. Wu. *Inonotus* is a well-known species commonly used in traditional medicine to treat various ailments (Delgersaikhan et al. 2024; Yu et al. 2024). The genus produces white rot and exhibits a worldwide distribution (Wagner and Fischer 2002; Dai 2010), with 289 specific registered names and 128 species accepted worldwide (www.indexfungorum.org; accessed on 26 January 2025) (Wagner and Fischer 2002; Dai 2010; Zhou et al. 2016; Wu et al. 2022).

The genus *Kneiffiella* P. Karst belongs to the family Chaetoporellaceae Jülich (Hymenochaetales, Basidiomycota) and is typified by *Kneiffiella barba-jovis* (Bull.) P. Karst. Fungi of this genus prefer dark microhabitats that slowly dry on tree trunks, leading to particularly severe wood decay, such as on hollow areas and undersides (Běťák et al. 2021). They have resupinate, smooth to grandinioid, coralloid, or irpicoid basidiomata; a white to brown or ochraceous hymenial surface; a monomitic to pseudodimitic hyphal system; generative hyphae with clamp connections; tubular and clavate cystidia; cylindrical to utriform, or barrel-like, basidia with four sterigmata; and cylindrical to ellipsoid or allantoid, inamyloid, and acyanophilous basidiospores (Wang et al. 2021). According to the Index Fungorum (www.indexfungorum.org; accessed on 26 January 2025), the genus *Kneiffiella* has 84 specific registered names, with 40 species accepted worldwide (Běťák et al. 2021; Wang et al. 2021; Viner et al. 2024).

The genus *Xylodon* (Pers.) Gray belongs to the family Schizoporaceae Jülich (Hymenochaetales, Basidiomycota) and is typified by *Xylodon quercinus* (Pers.) Gray (Bernicchia and Gorjón 2010). *Xylodon* is a large genus of corticioid fungi with a cosmopolitan distribution (Guan et al. 2023; Yurchenko et al. 2024; Zhang et al. 2024a). Species of *Xylodon* inhabit dead wood of various sizes, ranging from twigs of several millimeters in diameter to large fallen trunks, and they cause white rot (Greslebin and Rajchenberg 2000; Kotiranta and Saarenoksa 2000; Girometta et al. 2020; Guan et al. 2023). In some cases, basidiomata of *Xylodon* species appear on the living parts of trees (Yurchenko 2008) and non-woody plant remains, such as fern rachises

(Kotiranta and Saarenoksa 2000), herb stems, fallen leaves (Viner et al. 2018), and dead polypore basidiomata (Viner et al. 2023). Fungi in this genus have resupinate or effuse, smooth basidiomata; a tuberculate, grandinioid, odontioid, coralloid, irpicoid, or poroid hymenial surface; a monomitic or dimitic hyphal system that is generative with clamp connections; different types of cystidia; utriform or suburniform basidia; and cylindrical to ellipsoid to globose basidiospores (Gray 1821; Bernicchia and Gorjón 2010; Zhang et al. 2024a). According to the Index Fungorum (www.indexfungorum.org; accessed on 26 January 2025), the genus *Xylodon* has 241 specific registered names, with 157 species accepted worldwide. Remarkably, new species have been described in this genus at an accelerated pace owing to advances in morphological taxonomy and molecular phylogeny (Luo et al. 2022; Qu et al. 2022; Guan et al. 2023; Yurchenko et al. 2024; Zhang et al. 2024a).

In addition, host specificity is essential for determining the taxonomy and phylogeny of Hymenochaetales, with various types identified in a series of studies, including angiosperms, gymnosperms, both angiosperms and gymnosperms, and bryophytes (Dai 2010; Zhao et al. 2024). Most species in Hymenochaetales are polyporous and corticioid fungi, whereas certain species, such as *Blasiphalia* Redhead, *Contumyces* Redhead, and *Rickenella* Raithelh, basidiomata in those taxa are agarics. Beyond morphological diversity, various trophic modes, including saprotrophs, parasites, and symbiotes (with both trees and moss), also exist within Hymenochaetales (Wang and Zhou 2024). Many new Hymenochaetales taxa have recently been described due to research on the diversity of wood-inhabiting fungi in Yunnan Province (Chen and Zhao 2020; Luo et al. 2021; Qu et al. 2022; Guan et al. 2023; Yuan and Zhao 2024; Zhang et al. 2024a). These studies provide an important foundation for further exploration of species diversity and taxonomic status within Hymenochaetales.

This study collected five new species of wood-inhabiting fungi from Yunnan Province, China. To clarify the taxonomic placement of these species, morphological and phylogenetic analyses based on the ITS and nLSU sequences were conducted to identify them as new species of *Botryobasidium*, *Inonotus*, *Kneiffiella*, and *Xylodon*. This study provides full descriptions, color photographs, detailed comparisons with closely related taxa, and phylogenetic placements of the five new species. New data have been added to the biodiversity research on the genera *Botryobasidium*, *Inonotus*, *Kneiffiella*, and *Xylodon*, further affirming the rich biodiversity of southwestern China.

Materials and methods

Sample collection and herbarium specimen preparation

The fresh basidiomata were collected on the fallen angiosperm branches from Yunnan Province, China, and collection information was recorded (Rathnayaka et al. 2024). The samples were photographed *in situ*, and fresh macroscopic details were recorded. Photographs were taken by a Nikon D7100 camera. All the photos were focus-stacked using Helicon Focus software. Macroscopic details were recorded, and the fruit bodies were transported to a field station where they were dried in an electric food dryer at 45 °C (Hu et al. 2022). Once dried, the

specimens were sealed in an envelope and zip-lock plastic bags and labeled (Zhang et al. 2024b). The dried specimens were deposited in the herbarium of the Southwest Forestry University (SWFC), Kunming, Yunnan Province, China.

Morphological studies

The macro-morphology was based on the fresh specimens, while the micro-morphology was studied based on dried specimens. The color terms in the description followed Anonymous (1969) and Petersen (1996). Micro-morphology was studied at magnifications of 1000 ×, using a Nikon Eclipse 80i microscope with phase contrast illumination. Melzer's reagent (IKI), Cotton Blue (CB), and 5% potassium hydroxide (KOH) were used. Drawings were made with the aid of a drawing tube. In the text, further abbreviations were used: IKI− = non-dextrinoid and non-amyloid, IKI+ = amyloid, CB− = acyanophilous, CB+ = cyanophilous, L = mean basidiospore length (arithmetic average of all basidiospores), W = mean basidiospore width (arithmetic average of all basidiospores), Q = variation in the L/W ratios, n = the number of basidiospores measured.

DNA Extraction, polymerase chain reaction, and sequencing genomic

The CTAB rapid plant genome extraction kit-DN14 (Aidlab Biotechnologies Co., Ltd., Beijing) was used to obtain DNA from dried specimens. PCR was performed according to the manufacturer's instructions with some modifications (Yang et al. 2023). The nuclear ribosomal ITS region was amplified with the primers ITS5 and ITS4 (White et al. 1990). The nuclear ribosomal nLSU gene was amplified with the primers LR0R and LR7 (Vilgalys and Hester 1990; Rehner and Samuels 1994). The PCR procedure for ITS was as follows: initial denaturation at 95 °C for 3 min, followed by 35 cycles at 94 °C for 40 s, 54 °C for 45 s, and 72 °C for 1 min; and a final extension at 72 °C for 10 min. The PCR procedure for nLSU was as follows: initial denaturation at 94 °C for 1 min, followed by 35 cycles at 94 °C for 30 s, 50 °C for 1 min, and 72 °C for 1.5 min; and a final extension at 72 °C for 10 min (Zhou et al. 2024c). All newly generated sequences were submitted to GenBank and are listed in Table 1.

Phylogenetic analyses

Sequences generated for this study were aligned with additional sequences downloaded from GenBank. Sequences were aligned using MAFFT v.7 (https://mafft.cbrc.jp/alignment/server/), adjusting the direction of nucleotide sequences according to the first sequence (accurate enough for most cases), and selecting the G-INS-i iterative refinement method (Katoh et al. 2019). Alignments were manually adjusted to maximize alignment and minimize gaps with BioEdit v.7.0.9 (Hall 1999). A dataset of concatenated ITS and nLSU sequences was used to determine the phylogenetic position of the new species. Maximum likelihood (ML) analysis was performed using the CIPRES Science Gateway based on the dataset using the RA×ML-HPC BlackBox tool, with setting RA×ML halt bootstrapping automatically and 0.25 for maximum hours and obtaining the best tree using ML search (Miller et al. 2010). Other parameters in ML analysis used default

Table 1. Names, sample numbers, locations, references, and corresponding GenBank accession numbers of the taxa used in this study. [New species are shown in bold; * is shown as type material, holotype; — indicates sequence unavailability].

Species	Sample No.	GenBank No.		Country	References
		ITS	nLSU		
Alloclavaria purpurea	H6047663	MF319055	MF318905	Finland	Cho et al. 2024
Alloclavaria purpurea	M. Korhonen 10305	MF319044	MF318895	Finland	Cho et al. 2024
Antrodia subserpens	Dai 13233	KP715309	KT968830	China	Chen and Cui 2015
Atheloderma mirabile	TAA 169235	DQ873592	DQ873592	Estonia	Larsson et al. 2006
Basidioradulum radula	LWZ 20201017-62	ON063684	ON063884	China	Wang et al. 2023
Blasiphalia pseudogrisella	P. Hoijer 4118	MF319047	MF318898	Finland	Cho et al. 2024
Blasiphalia pseudogrisella	P. Hoijer 4393	MF319048	MF318899	Estonia	Cho et al. 2024
Botryobasidium acanthosporum	Yuan18083*	PP229512	PP218361	China	Zhou et al. 2024c
Botryobasidium acanthosporum	Yuan16326	PP229497	—	China	Zhou et al. 2024c
Botryobasidium asperulum	RAS552	OR471090	OR470959	USA	Swenie et al. 2023
Botryobasidium asperulum	FP102150	OR471075	OR47094	USA	Swenie et al. 2023
Botryobasidium aureum	GEL 2910	AJ389783	—	Germany	Langer et al. 2000b
Botryobasidium bambusinum	CLZhao29916	PQ539057	PQ539060	China	Dong et al. 2024b
Botryobasidium bambusinum	CLZhao29936*	PQ539058	PQ539061	China	Dong et al. 2024b
Botryobasidium botryosum	KHL11081	AY463387	AY586638	Sweden	Larsson et al. 2004
Botryobasidium botryosum	AFTOL-ID 604	DQ267124	—	USA	Zhou et al. 2024c
Botryobasidium candicans	UC2022891	KP814227	—	USA	Vu et al. 2018
Botryobasidium candicans	UC2022944	KP814546	—	USA	Vu et al. 2018
Botryobasidium candicans	UC2022893	KP814200	—	USA	Vu et al. 2018
Botryobasidium coniferarum	LWZ20171016-15	OR557262	—	China	Dong et al. 2024b
Botryobasidium coniferarum	LWZ20210928-3*	OR557259	—	China	Dong et al. 2024b
Botryobasidium conspersum	AFTOL-ID 1766	DQ911612	DQ521414	USA	Cao et al. 2021
Botryobasidium daweishanense	CLZhao40061	PQ373983	—	China	Present study
Botryobasidium daweishanense	**CLZhao40061**	**PQ373983**	—	**China**	**Present study**
Botryobasidium daweishanense	**CLZhao40062***	**PQ373984**	**PQ373977**	**China**	**Present study**
Botryobasidium gossypirubiginosum	CLZhao 26052*	OR668924	OR708665	China	Zhou et al. 2024b
Botryobasidium incanum	CLZhao 26697*	OR668923	OR708664	China	Zhou et al. 2024b
Botryobasidium indicum	NFCCI4480	NR171230	—	India	Zhou et al. 2024b
Botryobasidium indicum	AMH:10054	MK391496	—	India	Zhou et al. 2024b
Botryobasidium indicum	hr5326	OP806032	—	China	Zhou et al. 2024b
Botryobasidium indicum	CLZhao21791	ON406471	—	China	Zhou et al. 2024b
Botryobasidium indicum	AMH:10054	MK391496	MK391493	India	Zhou et al. 2024b
Botryobasidium intertextum	UC2022959	KP814540	—	North American	Zhou et al. 2024b
Botryobasidium laeve	RAS762	OR471128	—	USA	Swenie et al. 2023
Botryobasidium leptocystidiatum	Yuan17548	PP209211	—	China	Zhou et al. 2024c
Botryobasidium leptocystidiatum	Yuan17708*	PP209197	—	China	Zhou et al. 2024c
Botryobasidium robustius	CBS:945.69	MH859491	MH871272	Czech Republic	Fukami et al. 2010
Botryobasidium simile	RAS793	OR471146	—	USA	Swenie et al. 2023
Botryobasidium simile	RAS794	OR471147	—	USA	Swenie et al. 2023
Botryobasidium simile	GEL2348	KP171641	DQ898730	Canada	Cao et al. 2021
Botryobasidium subcoronatum	RAS620 SV1	OR471110	—	USA	Swenie et al. 2023
Botryobasidium subcoronatum	RAS789	OR471144	—	USA	Swenie et al. 2023
Botryobasidium subcoronatum	FP101015	OR471077	—	USA	Swenie et al. 2023
Botryobasidium subcoronatum	FP151108	OR471078	—	USA	Swenie et al. 2023
Botryobasidium subcoronatum	AFTOL-ID 614	DQ200924	AY647212	USA	Cao et al. 2021
Botryobasidium subovalibasidium	Yuan18179*	PP209196	—	China	Zhou et al. 2024c
Botryobasidium subovalibasidium	Yuan16439	PP209199	—	China	Zhou et al. 2024c
Botryobasidium tubulicystidium	DK14139	OL436769	—	USA	Zhou et al. 2024b
Botryobasidium yunnanense	CLZhao24877*	OR668925	—	China	Zhou et al. 2024b
Bridgeoporus sinensis	Cui 10013	KY131832	KY131891	China	Cho et al. 2024
Bryoclavula phycophila	TNS F-79667	NR169921	LC508118	Japan	Masumoto and Degawa 2020

Species	Sample No.	GenBank No.		Country	References
		ITS	nLSU		
Bryoclavula phycophila	S-287-FB3	LC544109	LC544110	Japan	Masumoto and Degawa 2020
Bryopistillaria sagittiformis	IO.14.164	MT232349	MT232303	Sweden	Olariaga et al. 2020
Burgella lutea	Etayo 27623	KC336076	KC336075	Bolivia	Diederich et al. 2014
Burgoa verzuoliana	CBS 131.38	NR145334	NG058614	Japan	Cao et al. 2021
Cantharellopsis prescotii	H6059300	MF319051	MF318903	Finland	Cho et al. 2024
Cantharellus albidolutescens	BB 08.070*	KF981365	KF294646	Madagascar	Cao et al. 2021
Cantharellus alborufescens	AH44223	KR677493	KR677531	Spain	Olariaga et al. 2015
Cantharellus alborufescens	BB 12.075	KX907209	KX929161	Switzerland	Olariaga et al. 2017
Cantharellus ambohitantelyensis	BB 08.336*	KF981366	KF294656	Madagascar	Cao et al. 2021
Cantharellus amethysteus	BB 07.284	JN944020	KF294639	Slovakia	Olariaga et al. 2017
Cantharellus amethysteus	AH44796*	KR677512	KR677550	Spain	Olariaga et al. 2015
Cantharellus anzutake	TNS-F-61925*	LC085359	LC085415	Japan	Cao et al. 2021
Cantharellus californicus	OSC 122878 *	KX828768	KX828795	USA	Olariaga et al. 2017
Cantharellus cascadensis	OSC 75908	AY041181	AY041160	USA	Olariaga et al. 2015
Cantharellus chicagoensis	PRL8916	KP639201	KP639218	USA	Leacock et al. 2016
Cantharellus chicagoensis	PRL8332	KP639200	KP639214	USA	Leacock et al. 2016
Cantharellus cibarius	BIO-Fungi 10986*	KR677501	KR677539	Sweden	Olariaga et al. 2015
Cantharellus cyphelloides	TNS:F-61721*	NR154853	NG059027	Japan	Suhara and Kurogi 2015
Cantharellus decolorans	469/BB 08.278	NR154788	KF294654	Madagascar	Olariaga et al. 2017
Cantharellus ferruginascens	BIO-Fungi 11700	KR677486	KR677524	Spain	Olariaga et al. 2015
Cantharellus hygrophorus	BB 08.196*	KF981368	KF294650	Madagascar	Cao et al. 2021
Cantharellus lewisii	BB 07.003*	JN944021	JN940597	USA	Olariaga et al. 2015
Cantharellus pallens	BB 09.409	KX929162	KX907215	Italy	Olariaga et al. 2017
Cantharellus romagnesianus	AH44218	KX828784	KX828807	Spain	Olariaga et al. 2017
Cantharellus roseocanus	DAOM220723	KX828787	KX828810	Canada	Olariaga et al. 2017
Cantharellus sebosus	BB 08.234*	NR154789	KF294652	Madagascar	Cao et al. 2021
Cantharellus sebosus	BB 08.162	KF981371	KF294649	Madagascar	Cao et al. 2021
Cantharellus subalbidus	OSC 75937	AY041179	AY041149	USA	Dunham et al 2003
Cantharellus subincarnatus	BB 06.096	KF981372	KF294602	Madagascar	Cao et al. 2021
Cantharellus subminor	Yuan 13917*	MW980545	MW979522	China	Cao et al. 2021
Cantharellus subminor	Yuan 13925	MW980546	MW979523	China	Cao et al. 2021
Cantharellus subminor	Yuan 13926	MW980547	MW979524	China	Cao et al. 2021
Cantharellus tabernensis	BB 07.064	JN944012	JN940608	USA	Olariaga et al. 2015
Cantharellus tabernensis	BB 07.040	JN944013	JN940609	USA	Olariaga et al. 2015
Cantharellus tenuithrix	BB 07.125*	JN944017	JN940600	USA	Olariaga et al. 2017
Cantharellus vaginatus	HKAS55730*	HQ416692	HM594681	China	Cao et al. 2021
Cantharellus yunnanensis	Yuan 14539	MW980541	MW979514	China	Cao et al. 2021
Cantharellus yunnanensis	Yuan 14636	MW980542	MW979515	China	Cao et al. 2021
Ceratobasidium globisporum	CBS 569.83	DQ278942	MH873365	Australia	Cao et al. 2021
Ceratobasidium sp.	CAG6	AF354083	AF354083	USA	Gonzalez et al. 2001
Ceratorhiza hydrophila	E14504F	MT381956	MT381951	Ecuador	Adaku et al. 2020
Cerioporus squamosus	Cui 10595	KU189778	KU189809	China	Zhou et al. 2016
Clavulina cerebriformis	MCA4022*	NR121504	JN228222	Guyana	Cao et al. 2021
Clavulina cf. cristata	MES426	JN228225	JN228225	China	Cho et al. 2024
Clavulina cinereoglebosa	TH8561	JN228218	JN228232	Guyana	Cho et al. 2024
Clavulina cristata	JKU8	JN228227	JN228227	USA	Cho et al. 2024
Clavulina sp.	MB03-034	DQ202266	AY745694	USA	Cao et al. 2021
Coltricia abieticola	Cui 10321	KX364785	—	China	Unpublished
Coniferiporia qilianensis	Yuan 6424	NR_158318	NG_060411	China	Wu et al. 2022
Coniferiporia weirii	FP-134599-SP	MT420695	MT416461	China	Cho et al. 2024
Contumyces rosellus	MGW1462	MF319059	MF318912	USA	Cho et al. 2024
Cotylidia fbrae	FM639	NR_176148	NG_088193	China	Cho et al. 2024
Cotylidia sp.	AFTOL-700	AY854079	AY629317	USA	Cho et al. 2024
Craterellus atratoides	TH8473	JQ915103	JQ915129	Guyana	Wilson et al. 2012
Craterellus atratoides	TH9232*	JQ915111	NG042660	Guyana	Wilson et al. 2012

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		ITS	nLSU		
Craterellus atratus	MCA1070	JQ915092	JQ915118	Guyana	Wilson et al. 2012
Craterellus atratus	MCA990	JQ915100	JQ915126	Guyana	Wilson et al. 2012
Craterellus atrobrunneolus	Yuan 13878	MN902353	MN894058	China	Wilson et al. 2012
Craterellus badiogriseus	Yuan 14776*	MW980548	MW979532	China	Cao et al. 2021
Craterellus badiogriseus	Yuan 14779	MW980549	MW979533	China	Cao et al. 2021
Craterellus cinereofimbriatus	TH8999	JQ915104	JQ915130	Guyana	Wilson et al. 2012
Craterellus cinereofimbriatus	TH9075*	JQ915105	JQ915131	Guyana	Wilson et al. 2012
Craterellus croceialbus	Yuan 14623*	MW980572	MW979529	China	Cao et al. 2021
Craterellus croceialbus	Yuan 14647	MW980573	MW979530	China	Cao et al. 2021
Craterellus excelsus	TH7515	JQ915101	JQ915127	Guyana	Wilson et al. 2012
Craterellus excelsus	TH8235*	JQ915102	JQ915128	Guyana	Wilson et al. 2012
Craterellus fallax	AFTOL-ID 286	DQ205680	AY700188	USA	Cao et al. 2021
Craterellus indicus	PUN 3884*	NR119831	NG060387	India	Kumari et al. 2012
Craterellus luteus	GDGM48105*	MG727896	MG701171	China	Zhong et al. 2018
Craterellus luteus	GDGM46432	MG727897	MG727898	China	Zhong et al. 2018
Craterellus macrosporus	Yuan 14782	MW980574	MW979531	China	Cao et al. 2021
Craterellus olivaceoluteus	MCA3186	JQ915098	JQ915124	Guyana	Wilson et al. 2012
Craterellus olivaceoluteus	TH9205*	JQ915109	JQ915135	Guyana	Wilson et al. 2012
Craterellus parvogriseus	CAL 1533*	MF421099	MF421098	India	Cao et al. 2021
Craterellus Pleurotoides	MCA3124	JQ915097	JQ915123	Guyana	Wilson et al. 2012
Craterellus pleurotoides	TH9220	JQ915110	JQ915136	Guyana	Wilson et al. 2012
Craterellus strigosus	MCA1750	JQ915094	JQ915120	Guyana	Wilson et al. 2012
Craterellus strigosus	TH9204*	JQ915108	JQ915134	Guyana	Wilson et al. 2012
Cylindrosporus flavidus	Dai 13213	KP875564	KP875561	China	Wu et al. 2022
Dacrymyces australis	CBS:196.63	MH858261	MH869866	USA	Cao et al. 2021
Fasciodontia brasiliensis	MSK-F 7245a*	MK575201	MK598734	Brazil	Yurchenko et al. 2020a
Fasciodontia bugellensis	KAS-FD 10705a	MK575203	MK598735	France	Yurchenko et al. 2020a
Fasciodontia yunnanensis	CLZhao 6280	MK811275	MZ146327	China	Luo and Zhao 2021
Fibrodontia gossypina	AFTOL-ID 599	DQ249274	—	USA	Unpublished
Flaviporellus splitgerberi	JV 1908/6	MZ484525	MZ437386	French Guiana	Wu et al. 2022
Fomitiporella inermis	JV 0509/57K	KX181305	KX181346	USA	Ji et al. 2018
Fomitiporella subinermis	Dai 15114	KX181308	KX181344	China	Ji et al. 2018
Fomitiporella vietnamensis	Dai 18377*	NR_158436	NG_060441	Vietnam	Ji et al. 2018
Fomitiporia langloisii	MUCL 46375	EF429242	EF429225	USA	Decock et al. 2007
Fomitopsis pinicola	AFTOL 770	AY854083	AY684164	USA	Unpublisheded
Fulvifomes indicus	Yuan 5932	KC879261	JX866777	China	Wu et al. 2022
Fuscoporia ferruginosa	JV0408/28	KX961103	KY189103	China	Chen and Yuan 2017
Globulicium hiemale	Hjm 19007	DQ873595	DQ873595	Sweden	Larsson et al. 2006
Gyroflexus brevibasidiatus	IO.14.230	MT232351	MT232305	Sweden	Olariaga et al. 2020
Hastodontia halonata	HHB-17058	MK575207	MK598738	Mexico	Yurchenko et al. 2020a
Heterobasidion annosum	06129/6	KJ583211	KJ583225	China	Chen et al. 2014
Hirschioporus abietinus	Cui 2667	OQ449096	OQ449033	China	Cho et al. 2024
Hirschioporus abietinus	Dai 23760	OQ449039	OQ449034	China	Cho et al. 2024
Hirschioporus acontextus	Dai 19097	OQ449140	OQ449199	China	Cho et al. 2024
Hirschioporus acontextus	Dai 23793*	OQ449141	OQ449200	China	Cho et al. 2024
Hirschioporus beijingensis	Dai 18907	OQ449142	OQ449201	China	Cho et al. 2024
Hirschioporus beijingensis	Dai 23704*	OQ449143	OQ449202	China	Cho et al. 2024
Hirschioporus chinensis	Dai 20264	OQ449101	OQ449204	China	Cho et al. 2024
Hirschioporus chinensis	Dai 23048	OQ437349	OQ438002	China	Cho et al. 2024
Hirschioporus fuscoviolaceus	Dai 20988	OQ437357	OQ438006	Belarus	Cho et al. 2024
Hirschioporus fuscoviolaceus	Cui 10439	OQ437361	OQ438010	China	Cho et al. 2024
Hirschioporus fuscoviolaceus	KUC20131001-03	KJ668436	KJ668288	South Korea	Jang et al. 2015
Hirschioporus pubescens	Dai 17064*	OQ437377	OQ438019	China	Cho et al. 2024
Hirschioporus pubescens	Dai 23710	OQ512026	OQ449059	China	Cho et al. 2024
Hirschioporus tianschanicus	Dai 19067*	OQ448960	OQ449067	China	Cho et al. 2024

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Hirschioporus tianschanicus	Dai 19064	OQ437386	OQ449066	China	Cho et al. 2024
Holtermanniella Wattica	CBS 9496*	NR138371	NG058307	Antarctica	Cao et al. 2021
Hydnoporia olivacea	Dai 12789	KT828678	KT828679	USA	Yang et al. 2016
Hydnoporia tabacina	LWZ 20210924-26a	ON063651	ON063851	China	Wang et al. 2023
Hydnum albomagnum	AFTOL-ID 471	DQ218305	AY700199	USA	Cao et al. 2021
Hydnum albomagnum	Wei 10194	MW980550	MW979536	China	Cao et al. 2021
Hydnum albomagnum	Wei 10247	MW980551	MW979537	China	Cao et al. 2021
Hydnum Berkeleyanum	CAL 1656*	NR158533	NG070500	India	Cao et al. 2021
Hydnum Berkeleyanum	HKAS77834	KU612525	KU612667	China	Cao et al. 2021
Hydnum berkeleyanum	Wei 10375	MW980552	MW979538	China	Cao et al. 2021
Hydnum brevispinum	Wei 10214*	MW980578	MW979559	China	Cao et al. 2021
Hydnum cremeoalbum	HKAS92345	KU612619	KU612676	China	Cao et al. 2021
Hydnum ellipsosporum	FD3281	KX086215	KX086217	Switzer	Cao et al. 2021
Hydnum flabellatum	Yuan 14708*	MW980575	MW979556	China	Cao et al. 2021
Hydnum flavidocanum	Yuan 13903a*	MW980559	MW979545	China	Cao et al. 2021
Hydnum flavidocanum	Yuan 13900a	MW980560	MW979546	China	Cao et al. 2021
Hydnum jussii	Yuan 14008	MW980553	MW979539	China	Cao et al. 2021
Hydnum jussii	Yuan 14009	MW980554	MW979540	China	Cao et al. 2021
Hydnum longibasidium	Wei 10383*	MW980556	MW979541	China	Cao et al. 2021
Hydnum longibasidium	Wei 10367	MW980555	MW979542	China	Cao et al. 2021
Hydnum magnorufescens	voucher 161209	KU612549	KU612669	China	Cao et al. 2021
Hydnum minum	N.K.Zeng2819	KY407533	KY407528	China	An et al. 2017
Hydnum minum	Wei 10252	MW980557	MW979543	China	Cao et al. 2021
Hydnum minum	Wei 10260	MW980558	MW979544	China	Cao et al. 2021
Hydnum Pallidocroceum	Yuan 14023*	MW980568	MW979554	China	Cao et al. 2021
Hydnum pallidocroceum	Yuan 14017	MW980569	MW979555	China	Cao et al. 2021
Hydnum pallidomarginatum	Yuan 13928a*	MW980566	MW979552	China	Cao et al. 2021
Hydnum pallidomarginatum	Yuan 13940a	MW980567	MW979553	China	Cao et al. 2021
Hydnum repandum	H 6003710*	KX388650	—	Finland	Dong et al. 2024b
Hydnum sphaericum	Wei 10243*	MW980563	MW979549	China	Cao et al. 2021
Hydnum subolympicum	F1188765	KU612599	KU612653	USA	Cao et al. 2021
Hydnum Subrufescens	F1188749	KU612535	KU612663	USA	Cao et al. 2021
Hydnum tangerinum	Wei 10245*	MW980580	MW979561	China	Cao et al. 2021
Hydnum tenuistipitum	Wei 10410*	MW980576	MW979557	China	Cao et al. 2021
Hydnum ventricosum	Yuan 14536*	MW980561	MW979547	China	Cao et al. 2021
Hymenochaete rubiginosa	He 1049	JQ716407	JQ279667	China	He and Li 2012
Hyphodontia abieticola	GEL2924	DQ340332	—	Germany	Unpublished
Hyphodontia abieticola	KHL 12498	DQ873601	—	Sweden	Unpublished
Hyphodontia alutaria	GEL3183	DQ340318	—	Germany	Zhang et al. 2024a
Hyphodontia alutaria	KHL 11889	DQ873603	—	Sweden	Unpublished
Hyphodontia alutaria	KHL 11978	EU118631	—	Norway	Unpublished
Hyphodontia argut	Wu 0806-44	JN571548	—	China	Unpublished
Hyphodontia arguta	KHL11938	EU118632	—	Sweden	Larsson 2007
Hyphodontia borbonica	FR-0219441*	KR349240	—	France	Unpublished
Hyphodontia borbonica	FR-0219444	KR349241	—	France	Unpublished
Hyphodontia curvispora	1591a	DQ873615	—	Finland	Unpublished
Hyphodontia hastata	GEL2143	DQ340323	—	Germany	Unpublished
Hyphodontia hastata	GEL3124	DQ340311	—	Germany	Unpublished
Hyphodontia mongolica	Cui 13240	KY290985	—	China	Unpublished
Hyphodontia mongolica	Cui 13239*	KY290984	—	China	Unpublished
Hyphodontia pachyspora	LWZ20180905-6	MT319425	—	China	Wang et al. 2021
Hyphodontia pachyspora	LWZ 20170908-5*	MT319426	MT319160	China	Wang et al. 2021
Hyphodontia pallidula	KAS-GEL2097	DQ340317	—	Germany	Zhang et al. 2024a
Hyphodontia sp.	LWZ20180511-2	MT319418	—	China	Wang et al. 2021
Hyphodontia sp.	LWZ20170814-15	MT319417	—	China	Wang et al. 2021

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Hyphodontia subdetritica	TU114869	OP620786	–	France	Viner et al. 2023
Hyphodontia subdetritica	FR-0261087	KY081794	–	France	Unpublished
Hyphodontia subdetritica	FR-0261085	KY081793	–	France	Unpublished
Hyphodontia tropica	ICMP 13835	AF145586	–	China	Viner et al. 2023
Hyphodontia tropica	ICMP 13837	AF145587	–	China	Unpublished
Hyphodontia wongiae	LWZ20180417-16	MT319416	–	China	Wang et al. 2021
Hyphodontia wongiae	LWZ20180417-8	MT319415	–	China	Wang et al. 2021
Hyphodontia wongiae	LWZ20180414-16*	MT319414	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ 20170818-13	MT319420	MT319151	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ20180903-5	MT319423	–	China	Luo et al. 2022
Hyphodontia zhixiangii	LWZ20170820-31	MT319422	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ20170820-27	MT319421	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ20180903-9	MT319424	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ 20160909-8	KY440397	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ 20160909-4*	KY440396	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ 20160909-9	KY440398	–	China	Wang et al. 2021
Hyphodontia zhixiangii	LWZ20180904-12	MT319419	–	China	Wang et al. 2021
Inonotopsis subiculosa	Dai 14799	KU598212	KU598217	China	Unpublished
Inonotus andersonii	SFCC 50025	AY558599	AY558599	South Korea	Unpublished
Inonotus andersonii	JV 1209/66	KF446594	–	China	Unpublished
Inonotus andersonii	CS-65-92-14-B	OQ539568	–	Indiana	Unpublished
Inonotus boninensis	Dai 18868	MZ484601	–	Australia	Wu et al. 2022
Inonotus costaricensis	JV 1511/171J	MZ484602	–	USA	Wu et al. 2022
Inonotus cuticularis	JV 0609/22	MN318442	MN318442	Czech Republic	Wu et al. 2022
Inonotus dentiporus	MUCL 4227	MZ484608	–	Brazil	Wu et al. 2022
Inonotus griseus	LWZ 20130810-20*	KM434333	–	China	Zhou and Wang 2015
Inonotus henanensis	Dai 13157*	KP030783	KX832918	China	Zhou and Wang 2015
Inonotus henanensis	Dai 12220	MZ484603	–	China	Wu et al. 2022
Inonotus henanensis	Dai 13157	KX674581	–	China	Wu et al. 2022
Inonotus hispidus	Cui 11932	MZ484604	–	China	Wu et al. 2022
Inonotus hispidus	S45	EU282482	–	Spain	Wu et al. 2022
Inonotus krawtzewii	JV 8709/35	KF446598	–	China	Wu et al. 2022
Inonotus krawtzewii	PRM 607951	KF446600	–	China	Wu et al. 2022
Inonotus latemarginatus	Dai 9758*	KP030784	–	China	Zhou and Wang 2015
Inonotus micantissimus	URM90186	MG576057	–	Brazil	Wu et al. 2022
Inonotus nidus-pici	JV01076	MN318440	–	Czech Republic	Wu et al. 2022
Inonotus niveomarginatus	Dai 12318*	KC456245	–	China	Yu et al. 2013
Inonotus obliquus	JV 0408/36	KF446605	–	China	Wu et al. 2022
Inonotus obliquus	Dai 10715	MZ484606	–	Finland	Wu et al. 2022
Inonotus plorans	Yang 52	MZ484607	–	China	Wu et al. 2022
Inonotus portoricensis	JV 1504/121	MN318447	MN318447	Costa Rica	Unpublished
Inonotus pseudoglomeratus	JV1707/15J	MN318437	–	Costa Rica	Wu et al. 2022
Inonotus quercustris	193	AY072026	–	Argentina	Gottlieb et al. 2002
Inonotus radiatus	SAT-10-240-02	MT955156	MT955156	USA	Unpublished
Inonotus radiatus	HBAU15722	MW862276	–	China	Unpublished
Inonotus radiatus	HMAS 292289	OR237100	–	China	Unpublished
Inonotus radiatus	HMAS 281802	OR236984	–	China	Unpublished
Inonotus radiatus	MQ18R132-QFB30648	MN992228	–	Canada	Unpublished
Inonotus radiatus	DM1160	MT644872	–	Denmark	Unpublished
Inonotus radiatus	Cui 10321	KX364785	–	China	Unpublished
Inonotus rickii	Dai 12996	KC479128	–	China	Wu et al. 2022
Inonotus rickii	JV 1612/21J	MZ484609	–	China	Wu et al. 2022
Inonotus setulosocroceus	STE-U7801	KP279294	–	South Korea	Wu et al. 2022
Inonotus subglobisporum	**CLZhao 8331**	**PQ373985**	**–**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8387**	**PQ373986**	**PQ373978**	**China**	**Present study**

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Inonotus subglobisporum	**CLZhao 8433**	**PQ373987**	**PQ373979**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8453**	**PQ373988**	**—**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8500**	**PQ373989**	**PQ373980**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8678**	**PQ373990**	**—**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8737**	**PQ373991**	**—**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8765***	**PQ373992**	**—**	**China**	**Present study**
Inonotus subglobisporum	**CLZhao 8789**	**PQ373993**	**—**	**China**	**Present study**
Inonotus subradiatus	Dai 20201*	MZ484610	—	China	Wu et al. 2022
Inonotus tenuicontextus	Yuan 5526*	NR_119969	—	China	Zhou and Qin 2011
Inonotus ulmicola	H 6012614	KF446606	—	China	Wu et al. 2022
Inonotus ungulatus	Dai 18864	MZ484611	—	Australia	Wu et al. 2022
Inonotus vieinamensis	Dai 18310	MZ484613	—	Viet Nam	Wu et al. 2022
Inonotus vieinamensis	Dai 18288*	MZ484612	—	Viet Nam	Zhou and Qin 2011
Inonotus vitis	OC 1*	MN108118	MN113944	USA	Brown et al .2019
Kneiffiella barba-jovis	KHL 11730	DQ873609	DQ873610	Sweden	Unpublished
Kneiffiella subglobosa	LWZ 20180416-6	MT319413	MT319145	China	Wang et al. 2021
Kneiffiella abdita	Miettinen 22165	ON188809	ON188809	Finland	Viner et al. 2024
Kneiffiella abieticola	KHL 12498 (GB)	DQ873601	—	Sweden	Larsson et al. 2006
Kneiffiella alienata	CBS 127219	MH864327	—	USA	Vu et al. 2018
Kneiffiella altaica	PRM 956491	OM971678	—	Czech Republic	Langer et al. 2022
Kneiffiella altaica	PRM 956489	OM971676	—	Czech Republic	Langer et al. 2022
Kneiffiella altaica	PRM 956490	OM971677	—	Czech Republic	Langer et al. 2022
Kneiffiella altaica	PRM 953309	OM971675	—	Czech Republic	Langer et al. 2022
Kneiffiella alutacea	KAS-GEL 2284	DQ340340	—	Germany	Yurchenko et al. 2020a
Kneiffiella alutacea	Miettinen 21701	ON188808	ON188808	Finland	Viner et al. 2024
Kneiffiella barba-jovis	KHL 11730	DQ873609	—	Sweden	Larsson et al. 2006
Kneiffiella bubalina	**CLZhao 15708***	**PQ373994**	**—**	**China**	**Present study**
Kneiffiella cineracea	KAS-GEL 4958	DQ340336	—	Germany	Yurchenko et al. 2020a
Kneiffiella curvispora	PRM 954540	MW345630	—	Slovakia	Běťák et al. 2021
Kneiffiella curvispora	Pennanen 4040	OP620787	OP620787	Finland	Viner et al. 2024
Kneiffiella decorticans	SP 415980	KY081795	—	Argentina	Riebesehl and Langer 2017
Kneiffiella efibulata	GB-0151167,	KY081796	—	Sweden	Riebesehl and Langer 2017
Kneiffiella eucalypticola	LWZ20180515-9	MT319411	—	Australia	Luo et al. 2022
Kneiffiella eucalypticola	LWZ 20180509-11*	MT319410	MT319142	China	Wang et al. 2021
Kneiffiella floccosa	UC 2022902	KP814441	—	USA	Rosenthal et al. 2017
Kneiffiella microspora	Miettinen 11418	OP620788	OP620788	Indonesia	Viner et al. 2024
Kneiffiella palmae	FR 7	KP689185	—	China	Wang et al. 2016
Kneiffiella palmae	KAS-GEL 3456	DQ340333	—	China	Yurchenko et al. 2020a
Kneiffiella pilaecystidiata	MSK-F 4723	MK575208	—	Belarus	Yurchenko et al. 2020a
Kneiffiella pilaecystidiata	Helo 1517	OP620789	OP620789	Finland	Viner et al. 2024
Kneiffiella pseudoabdita	LWZ 20210624-6b*	OQ540894	—	China	Liu et al. 2024
Kneiffiella pseudoalutacea	LWZ 20210625-5b*	OQ540895	—	China	Liu et al. 2024
Kneiffiella stereicola	Blackwell 2141*	KY081797	—	USA	Riebesehl and Langer 2017
Kneiffiella subaltaica	HHB-20039*	OM971679	—	USA	Langer et al. 2022
Kneiffiella subalutacea	KAS-GEL 2196	DQ340341	—	Norway	Yurchenko et al. 2020a
Kneiffiella subalutacea	KAS-GEL2196	DQ340341	—	Norway	Yurchenko et al. 2020a
Kneiffiella subefibulata	Dai 10803	KT989971	—	China	Chen et al. 2016
Kneiffiella subglobosa	Wu 890805-2	KY081798	—	Taiwan	Riebesehl and Langer 2017
Lawrynomyces capitatus	KHL 8464	DQ677491	DQ677491	Sweden	Cho et al. 2024
Leifia brevispora	LWZ 20170820-48	MK343470	MK343474	China	Liu et al. 2019
Leucophellinus hobsonii	Cui 6468	KT203288	KT203309	China	Cho et al. 2024
Leucophellinus irpicoides	Yuan 2690	KT203289	KT203310	China	Cho et al. 2024
Lyomyces allantosporus	FR 0249548*	KY800397	KY795963	Reunion	Yurchenko et al. 2017
Lyomyces bambusinus	CLZhao 4831*	MN945968	MW264919	China	Chen and Zhao 2020
Lyomyces fimbriatus	Wu 911204-4	MK575210	MK598740	China	Yurchenko et al. 2020a

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Lyomyces mascarensis	KASGEL 4833*	KY800399	KY795964	Reunion	Yurchenko et al. 2020a
Lyomyces niveus	CLZhao 6431	MZ262541	MZ262526	China	Unpublished
Lyomyces niveus	CLZhao 6442	MZ262542	MZ262527	China	Unpublished
Lyomyces ochraceoalbus	CLZhao 4385	MZ262535	MZ262521	China	Unpublished
Lyomyces ochraceoalbus	CLZhao 4725	MZ262536	MZ262522	China	Unpublished
Lyomyces orientalis	LWZ 20170909-7	MT319436	MT319170	China	Luo et al. 2022
Lyomyces sambuci	KASJR 7	KY800402	KY795966	Germany	Yurchenko et al. 2017
Meganotus everhartii	JV 0108/30	MZ484529	MZ437388	USA	Unpublished
Minimedusa obcoronata	CBS 120605	GQ303278	GQ303309	Thailand	Cheewangkoon et al. 2009
Minimedusa polyspora	CBS 113.16*	MH854646	MH866167	USA	Cao et al. 2021
Multiclavula corynoides	Lutzoni 930804-2	U66440	U66440	USA	Cao et al. 2021
Multiclavula Mucida	TUB 011734	EU909345	EU909345	Germany	Cao et al. 2021
Multiclavula petricola	356 ex*	LC516464	LC516465	Japan	Cao et al. 2021
Multiclavula Vernalis	Lutzoni 930806-1	U66439	U66439	USA	Cao et al. 2021
Muscinupta laevis	V. Haikonen 19745	MF319066	MF318921	Finland	Cho et al. 2024
Neoburgoa freyi	LF1256*	KX423756	KX423756	Switzerland	Lawrey et al. 2016
Neoburgoa freyi	JL596-16	KX423754	KX423755	Switzerland	Lawrey et al. 2016
Neomensularia duplicata	LWZ 20150529-4	KX078217	KX078221	China	Wu et al. 2016
Neophellinus uncisetus	MUCL 47061	GU461972	GU462000	Argentina	Amalfi et al. 2010
Nigrohirschioporus durus	Dai 20642	OL470321	OL462835	China	Cho et al. 2024
Nigrohirschioporus durus	He 20120724-11	OQ448973	OQ449076	China	Cho et al. 2024
Nigrohirschioporus griseofuscus	B3942	OQ448975	OQ438022	Brazil	Cho et al. 2024
Nigrohirschioporus griseofuscus	JV 1909/ 6	OQ437343	OQ438024	French Guiana	Cho et al. 2024
Nigrohirschioporus sector	AS 2707	OQ437344	OQ438025	Brazil	Cho et al. 2024
Nigrohirschioporus trimiticus	B696*	OQ453308	OQ453535	Brazil	Cho et al. 2024
Nothophellinus andinopatagonicus	JV 1911/20	MZ484532	MZ437391	Chile	Wu et al. 2022
Oliveonia subfibrillosa	TH 2018074	MT235650	MT235618	Finland	Cao et al. 2021
Oliveonia subfibrillosa	TH 2018179	MT235649	MT235617	Finland	Cao et al. 2021
Oliveonia subfibrillosa	VS 9048	MT235647	MT235615	Russia	Cao et al. 2021
Oliveonia subfibrillosa	VS 9053	MT235645	MT235614	Russia	Cao et al. 2021
Onnia tomentosa	Dai 22935	OL473604	OL473617	China	Cho et al. 2024
Onnia tomentosa	Niemela 9079	MF319075	MF318931	Finland	Wu et al. 2022
Pachynotus punctatus	Dai 17803*	MZ484535	MZ437394	Singapore	Wu et al. 2022
Pallidohirschioporus biformis	Dai 12746	OQ453311	OQ453538	USA	Cho et al. 2024
Pallidohirschioporus biformis	Dai 19466	OQ453223	OQ453548	China	Cho et al. 2024
Pallidohirschioporus brastagii	Dai 22919	OQ453371	OQ453297	China	Cho et al. 2024
Pallidohirschioporus polycystidiatus	Dai 19100	OQ453378	OQ453301	China	Cho et al. 2024
Pallidohirschioporus versicolor	Dai 19331	OQ453386	OQ474951	China	Cho et al. 2024
Peniophorella aspersa	CLZhao 17063	OM985730	OM985771	China	Cho et al. 2024
Peniophorella aspersa	F24809*	NR_172775	NG_073750	China	Yurchenko et al. 2020b
Peniophorella crystallifera	F23666*	NR_171802	NG_073751	China	Yurchenko et al. 2020b
Peniophorella crystallifera	LWZ 20210626-4a	ON063685	ON063885	China	Wang et al. 2023
Peniophorella fissurata	CLZhao 9421*	NR177497	NG154027	China	Guan et al. 2020
Peniophorella odontiiformis	CLZhao 9862	MT247004	OM985779	China	Cho et al. 2024
Peniophorella odontiiformis	SFC20150108-37	OQ996168	OQ996199	South Korea	Cho et al. 2024
Peniophorella pallida	CLZhao 3017	OM985738	OM985780	China	Cho et al. 2024
Peniophorella praetermissa	AFTOL-ID 518	AY854081	AY700185	USA	Cho et al. 2024
Peniophorella praetermissa	LWZ 20180903-14	ON063686	ON063886	China	Wang et al. 2023
Peniophorella pubera	LWZ 20210624-16b	ON063687	ON063887	China	Wang et al. 2023
Peniophorella reticulata	F22559*	NR172776	NG073752	China	Yurchenko et al. 2020b
Peniophorella rude	F30649	MN062105	MN062153	China	Yurchenko et al. 2020b
Peniophorella rude	LWZ 20171026-7	ON063688	ON063888	China	Wang et al. 2023
Peniophorella subpraetermissa	LWZ 20190816-3b	ON063689	ON063889	China	Wang et al. 2023
Perennihirschioporus variabilis	B856	OQ474942	OQ474957	Brazil	Cho et al. 2024
Perenninotus shoreicola	Dai 13614	KJ575522	KT749416	Thailand	Wu et al. 2022

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		ITS	nLSU		
Phellinidium ferrugineofuscum	Cui 10042	KC782527	KC782529	China	Wu et al. 2022
Phellinopsis conchata	L-7601	KU139188	KU139257	USA	Brazee 2015
phylloporia gabonensis	MUCL 55571	NR_154331	NG_059641	Gabon	Unpublished
phylloporia nodostipitata	FLOR 51173*	KJ639055	KJ631412	Brazil	Wu et al. 2022
phylloporia perangusta	Dai 18139	MH151169	MG738803	China	Wu et al. 2022
Porodaedalea pini	No-6170-T	JX110037	JX110081	Porrugal	Brazee and Lindner 2013
Pseudoinonotus dryadeus	JV 1907/7	MZ484540	MZ437400	Czechia	Wu et al. 2022
Pyrrhoderma adamantinum	Dai 13832	MF860790	MF860736	China	Wu et al. 2022
Resinicium austroasianum	LWZ 20180417-5*	NR173962	NG088188	China	Yu et al. 2021
Resinicium austroasianum	LWZ 20191208-11	ON063691	ON063891	China	Wang et al. 2023
Resinicium bicolor	AFTOL-810	DQ218310	AF393061	USA	Cho et al. 2024
Resinicium lateastrocystidium	LWZ 20180414-15*	NR173963	MW414455	China	Yu et al. 2021
Resinicium lateastrocystidium	LWZ 20180416-10	MW414510	MW414456	China	Yu et al. 2021
Resinicium monticola	FP-150360*	NR_111226	DQ863697	Jamaica	Cho et al. 2024
Resinicium mutabile	FP-102989*	NR_119612	DQ863699	Puerto Rico	Cho et al. 2024
Resinicium rimulosum	KUC20131022-12	KJ668464	KJ668315	South Korea	Jang et al. 2016
Rhizoctonia solani	BRS17	MK481078	MN078809	India	Cao et al. 2021
Rickenella fibula	HBK013	MF319081	MF318941	USA	Cho et al. 2024
Rickenella fibula	SFC20230704-06	OR758634	OR758646	South Korea	Cho et al. 2024
Rickenella fibula	RAS051	MF319094	MF318972	USA	Cho et al. 2024
Rickenella fibula	HBK016	MF319084	MF318944	USA	Cho et al. 2024
Rickenella fibula	HBK014	MF319082	MF318942	USA	Cho et al. 2024
Rickenella indica	SFC20140626-39	OQ996172	OQ996203	South Korea	Cho et al. 2024
Rickenella mellea	CBS 579.87	MH862106	MH873795	France	Vu et al. 2018
Rickenella mellea	CBS 581.87	MH862107	MH873796	France	Vu et al. 2018
Rickenella minuta	MES1950	MF319097	MF318964	Argentina	Cho et al. 2024
Rickenella minuta	MES1892	MF318966	MF288881	Argentina	Cho et al. 2024
Rickenella minuta	MES1965	MF319105	MF318963	Argentina	Cho et al. 2024
Rickenella umbelliformis	SFC20150701-65*	OQ996173	OQ996204	South Korea	Cho et al. 2024
Rickenella umbelliformis	SFC20160713-77	OQ996175	OQ996205	South Korea	Cho et al. 2024
Rickenella umbelliformis	SFC20180704-81	OQ996176	OQ996206	South Korea	Cho et al. 2024
Rigidoporus corticola	KUC20130718-79	KJ668502	KJ668354	South Korea	Jang et al. 2016
Rigidoporus corticola	LWZ 20190819-3b	ON063673	ON063872	China	Wang et al. 2023
Rigidoporus corticola	SFC20230816-48	OR758635	OR758647	South Korea	Cho et al. 2024
Rigidoporus cuneatus	Cui 10855	OQ930254	OQ924530	South Korea	Cho et al. 2024
Rigidoporus cuneatus	Dai 7339	KT203294	KT203315	China	Cho et al. 2024
Rigidoporus ginkgonis	Cui 5555	KT203295	KT203316	China	Cho et al. 2024
Rigidoporus ginkgonis	SFC20230630-23	OR758636	OR758648	South Korea	Cho et al. 2024
Rigidoporus juniperinus	YG 1070	MK433641	MK433643	Uzbekistan	Cho et al. 2024
Rigidoporus juniperinus	Dai 17100	OQ930261	OQ924537	Uzbekistan	Cho et al. 2024
Rogersiomyces malaysianus	LE-BIN 3507-10	KT779285	KU820986	Vietnam	Cao et al. 2021
Sanghuangporus weigelae	LWZ 20210623-2a	ON063671	ON063870	China	Wang et al. 2023
Sanghuangporus zonatus	Dai 10841	OP962417	KP030775	China	Wu et al. 2022
Schizocorticium lenis	LWZ 20180921-7*	MW414521	MW414467	China	Yu et al. 2021
Schizocorticium magnosporum	Wu 1510-34*	MK405351	MK405337	China	Wang and Zhou 2024
Schizocorticium mediosporum	Chen 2456*	MK405359	MK405345	China	Wang and Zhou 2024
Schizocorticium parvosporum	GC 1508-127*	MK405361	MK405347	China	Wang and Zhou 2024
Sidera minutipora	Cui 16720	MN621349	MN621348	Australia	Wang and Zhou 2024
Sidera minutissima	Dai 19529	MN621352	MN621350	Sri Lanka	Du et al. 2020
Sidera parallela	Dai 22038	MW477793	MW474964	China	Cho et al. 2024
Sidera srilankensis	Dai 19654*	NR_172780	NG_075310	Sri Lanka	Cho et al. 2024
Sidera tenuis	Dai 18697*	NR_171833	NG_075283	Singapore	Cho et al. 2024
Sidera tibetica	SFC20230317-17	OQ996177	OQ996207	South Korea	Cho et al. 2024
Sidera tibetica	Dai 23648*	NR_177641	OM974245	China	Liu et al. 2022
Sidera vesiculosa	BJFC 025377*	NR164588	NG066418	Singapore	Cho et al. 2024

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Sidera vulgaris	Dai 21057	MW198484	MW192009	Singapore	Liu et al. 2021
Sistotrema confluens	FCUG298	DQ267125	AY647214	USA	Cao et al. 2021
Sistotrema confluens	PV174	AY463466	AY586712	Czechia	Larsson et al. 2004
Sistotrema subconfluens	Dai 12577	JX076812	JX076810	China	Zhou and Qin 2013
Sistotremella perpusilla	CBS 126048	MH864061	MH875516	USA	Cao et al. 2021
Skvortzovia dabieshanensis	LWZ 20201012-22*	NR_173964	NG_088189	China	Yu et al. 2021
Skvortzovia dabieshanensis	LWZ 20210918-15b	ON063694	ON063894	China	Yu et al. 2021
Skvortzovia pinicola	LWZ 20210623-18b	ON063695	ON063895	China	Wang et al. 2023
Skvortzovia qilianensis	LWZ 20180904-16*	NR173965	NG088190	China	Yu et al. 2021
Skvortzovia qilianensis	LWZ 20180904–20	MW414520	MW414466	China	Yu et al. 2021
Skvortzovia yunnanensis	CLZhao 16084	MW472754	MW473473	China	Dong et al. 2021
Trichaptum byssogenum	Dai 15555	OQ449085	OQ449026	China	Cho et al. 2024
Trichaptum perrottetii	JV 1908/ 45	OQ449092	OQ449031	French Guiana	Cho et al. 2024
Trichosporon insectorum	CBS 10422*	KF036603	KY109953	Panama	Cao et al. 2021
Tubulicrinis accedens	MICH:352299	OL756001	OL742444	USA	Cho et al. 2024
Tubulicrinis calothrix	LWZ 20210919-1b	ON063704	ON063904	China	Wang et al. 2023
Tubulicrinis glebulosus	LWZ 20180903-13	ON063705	ON063905	China	Wang et al. 2023
Tubulicrinis subulatus	LWZ 20190914-7	ON063706	ON063906	China	Wang et al. 2023
Tubulicrinis xantha	CLZhao 2869	MT153875	MT153882	China	He et al. 2020
Tulasnella asymmetrica	AFTOL-ID 1678	DQ520101	DQ520101	Germany	Cao et al. 2021
Tulasnella irregularis	CBS 574.83	NR160166	NG057720	Australia	Cao et al. 2021
Tulasnella pruinosa	DAOM 17641	DQ457642	AF518662	USA	Cao et al. 2021
Tulasnella violea	AFTOL-ID 1879	DQ520097	DQ520097	Germany	Cao et al. 2021
Xylodon acuminatus	Larsson 16029	ON197552	–	Brazil	Viner et al. 2023
Xylodon acystidiatus	LWZ 20180514-9*	MT319474	MT319211	Australia	Luo et al. 2022
Xylodon afromontanus	H 7006811*	OQ645463	–	Rwanda	Yurchenko et al. 2024
Xylodon angustisporus	Ryvarden 50691b*	OK273831	–	Cameroon	Viner et al. 2021
Xylodon apacheriensis	Wu 0910-58	KX857797	KX857822	China	Chen et al. 2017
Xylodon apacheriensis	Canfield 180	KY081800	–	USA	Wang et al. 2021
Xylodon asiaticus	CLZhao 2282	OM959481	OM967416	China	Zhang et al. 2024a
Xylodon asiaticus	CLZhao 10368*	OM959479	OM967417	China	Zhang et al. 2024a
Xylodon asiaticus	CLZhao 10430	OM959480	OM967418	China	Zhang et al. 2024a
Xylodon asiaticus	CLZhao 2282	OM959481	OM967416	China	Zhang et al. 2024a
Xylodon asperus	Spirin 11923	OK273838	–	Russia	Viner et al. 2021
Xylodon astrocystidiatus	TNM F24764	NR154054	–	China	Yurchenko and Wu 2014
Xylodon astrocystidiatus	Wu 9211-71*	JN129972	JN129973	China	Yurchenko and Wu 2014
Xylodon attenuatus	Spirin 8775*	MH324476	–	America	Wang et al. 2021
Xylodon australis	LWZ 20180509-8	MT319503	–	China	Wang et al. 2021
Xylodon bambusinus	CLZhao 11310*	MW394660	–	China	Ma and Zhao 2021
Xylodon bambusinus	CLZhao 9174	MW394657	MW394650	China	Ma and Zhao 2021
Xylodon bambusinus	CLZhao 9174	MW394657	MW394650	China	Ma and Zhao 2021
Xylodon borealis	JS 26064	AY463429	–	Norway	Larsson et al. 2004
Xylodon brevisetus	JS 17863	AY463428	–	Norway	Larsson et al. 2004
Xylodon crystalliger	LWZ 20170816-33	MT319521	MT319269	China	Luo et al. 2022
Xylodon crystalliger	KUN 2312*	NR166242	–	China	Viner et al. 2018
Xylodon cymosus	Miettinen 19606*	ON197554	–	USA	Viner et al. 2023
Xylodon cystidiatus	FR 0249200	MH880195	MH884896	France	Riebesehl et al. 2019
Xylodon damansaraensis	LWZ 20180417-23	MT319499	–	Malaysia	Wang et al. 2021
Xylodon daweishanense	CLZhao 18357	OP730715	–	China	Guan et al. 2023
Xylodon daweishanense	CLZhao 18492	OP730719	–	China	Guan et al. 2023
Xylodon detriticus	Zíbarová 30.10.17	MH320793	–	Czech Republic	Wang et al. 2021
Xylodon dissiliens	Ryvarden 44817*	OK273856	–	Uganda	Viner et al. 2021
Xylodon echinatus	OM 18237	OQ645464	–	Indonesia	Yurchenko et al. 2024
Xylodon exilis	TUB-FO42565*	MH880198	MH884898	China	Riebesehl et al. 2019
Xylodon filicinus	MSKF 12869*	MH880199	NG067836	China	Riebesehl et al. 2019

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Xylodon fissuratus	CLZhao 9407*	OP730714	–	China	Guan et al. 2023
Xylodon flaviporus	FR-0249797	MH880201	MH884901	Reunion	Riebesehl et al. 2019
Xylodon flocculosus	CLZhao 18342*	MW980776	–	China	Qu and Zhao 2022
Xylodon follis	FR-0249814*	MH880204	MH884902	Reunion	Riebesehl et al. 2019
Xylodon gloeocystidiifer	BLS M-5232*	OQ645467	–	Ecuador	Yurchenko et al. 2024
Xylodon gloeocystidiifer	EYu 190720-11	OR240822	–	Ecuador	Unpublished
Xylodon gossypinus	CLZhao 4465	MZ663803	MZ663812	China	Luo et al. 2021
Xylodon gossypinus	CLZhao 8375*	MZ663804	–	China	Luo et al. 2021
Xylodon gossypinus	CLZhao 4465	MZ663803	MZ663812	China	Luo et al. 2021
Xylodon grandineus	CLZhao 6425	OM338090	–	China	Luo et al. 2022
Xylodon granulanoides	**CLZhao 17253***	**PQ373995**	**PQ373981**	**China**	**Present study**
Xylodon granulans	**CLZhao 17804**	**PQ373996**	**–**	**China**	**Present study**
Xylodon granulans	**CLZhao 17866***	**PQ373997**	**PQ373982**	**China**	**Present study**
Xylodon hastifer	K(M) 172400*	NR166558	–	America	Riebesehl and Langer 2017
Xylodon heterocystidiatus	LWZ20180921-19	MT319676	MT319266	Australia	Zhang et al 2024a
Xylodon heterocystidiatus	Wei 17-314	MT731753	MT731754	China	Zhang et al. 2024a
Xylodon hjortstamii	Gorjon 3187	ON188816	–	Chile	Yuan and Zhao 2024
Xylodon hyphodontinus	KAS-GEL9222	MH880205	–	Kenya	Riebesehl et al. 2019
Xylodon jacobaeus	MA-Fungi 91340*	MH430073	–	Spain	Wang et al. 2021
Xylodon kunmingensis	TUB-FO 42565	MH880198	–	China	Wang et al. 2021
Xylodon laceratus	CLZhao 9892*	OL619258	OL619266	China	Qu et al. 2022
Xylodon lagenicystidiatus	LWZ 20180513-16*	MT319634	MT319368	Australia	Luo et al. 2022
Xylodon lanatus	CFMR FP-101864-A*	OQ645474	–	USA	Yurchenko et al. 2024
Xylodon lenis	Wu 890714-3	KY081802	–	China	Riebesehl et al. 2019
Xylodon macrosporus	CLZhao 10226*	MZ663809	MZ663817	China	Luo et al. 2021
Xylodon magallanesii	MA: Fungi:90397*	MT158729	–	Chile	Fernandez-Lopez et al. 2020
Xylodon mantiqueirensis	MV 529	OQ645478	–	Brazil	Yurchenko et al. 2024
Xylodon mollissimus	LWZ 20160318-3*	KY007517	MT319347	China	Luo et al. 2022
Xylodon montanus	CLZhao 8179*	OL619260	OL619268	China	Qu et al. 2022
Xylodon muchuanensis	LWZ 20200819-3a	OQ540903	–	China	Unpublished
Xylodon muchuanensis	LWZ 20200819-2b*	OQ540902	–	China	Unpublished
Xylodon neotropicus	MV 580	OQ645479	–	Brazil	Yurchenko et al. 2024
Xylodon nesporii	LWZ 20180921-35	MT319655	MT319238	China	Luo et al. 2022
Xylodon niemelaei	LWZ 20150707-13	MT319630	MT319365	China	Luo et al. 2022
Xylodon nongravis	GC 1412-22*	KX857801	KX857818	China	Chen et al. 2017
Xylodon nothofagi	ICMP 13842	AF145583	–	China	Wang et al. 2021
Xylodon ovisporus	LWZ 20170815-31	MT319666	MT319346	China	Luo et al. 2022
Xylodon papillosus	CBS 114.71	MH860026	–	Netherlands	Vu et al. 2018
Xylodon paradoxus	Dai 14983	MT319519	MT319267	China	Luo et al. 2022
Xylodon patagonicus	ICMP 13832	AF145581	–	Argentina	Wang et al. 2021
Xylodon pruinosus	Spirin 2877	MH332700	–	Estonia	Wang et al. 2021
Xylodon pruniaceus	Ryvarden 11251	OK273828	–	Malawi	Viner et al. 2021
Xylodon pseudolanatus	FP 150922*	MH880220	NG067837	Belize	Riebesehl et al. 2019
Xylodon pseudotropicus	Dai 16167	MT319509	MT319255	China	Luo et al. 2022
Xylodon pseudotropicus	Dai 10768*	KF917543	–	China	Wang et al. 2021
Xylodon pseudotropicus	Dai 16167	MT319509	MT319255	China	Luo et al. 2022
Xylodon puerensis	CLZhao 8142*	OP730720	–	China	Guan et al. 2023
Xylodon punctus	CLZhao 17691*	OM338092	–	China	Luo et al. 2022
Xylodon punctus	CLZhao 17908	OM338093	–	China	Luo et al. 2022
Xylodon quercinus	Otto Miettinen 15050,1	KT361632	–	Finland	Ariyawansa et al. 2015
Xylodon quercinus	Spirin 12030	OK273841	–	Russia	Viner et al. 2021
Xylodon quercinus	Otto Miettinen 15050,1	KT361632	–	Finland	Ariyawansa et al. 2015
Xylodon quercinus	KHL 11076	KT361633	AY586678	Sweden	Larsson et al. 2004
Xylodon quercinus	KHL 11076	KT361633	AY586678	Sweden	Larsson et al. 2004
Xylodon raduloides	FCUG 2433	AF145570	–	Russia	Wang et al. 2021

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		ITS	nLSU		
Xylodon ramicida	Spirin 7664*	NR138013	–	America	Yuan and Zhao 2024
Xylodon reticulatus	Wu 1109-178	KX857805	–	China	Wang et al. 2021
Xylodon reticulatus	GC 1512-1	KX857808	–	China	Wang et al. 2021
Xylodon rhizomorphus	Dai 12367*	NR154067	–	China	Wang et al. 2021
Xylodon rhododendricola	LWZ 20180513-9	MT319621	MT319357	Australia	Luo et al. 2022
Xylodon rimosissimus	Ryberg 021031	DQ873627	DQ873628	Sweden	Larsson et al. 2006
Xylodon serpentiformis	LWZ 20170816-15	MT319673	MT319218	China	Luo et al. 2022
Xylodon sinensis	CLZhao 9197	MZ663810	MZ663818	China	Luo et al. 2021
Xylodon sinensis	CLZhao 11120*	OK560885	–	China	Luo et al. 2021
Xylodon spathulatus	LWZ 20180804-10	MT319646	MT319354	China	Luo et al. 2022
Xylodon subclavatus	FO 42167	MH880232	–	China	Wang et al. 2021
Xylodon subflaviporus	Wu 0809-76	KX857803	KX857815	China	Chen et al. 2017
Xylodon subflaviporus	TNM F29958*	NR184880	–	China	Chen et al. 2017
Xylodon subpunctus	CLZhao 6165	PP537958	–	China	Unpublished
Xylodon subpunctus	CLZhao 31242*	PP537957	–	China	Unpublished
Xylodon subserpentiformis	LWZ 20180512-16	MT319486	MT319226	Australia	Luo et al. 2022
Xylodon subtilissimus	Spirin 12228	ON188818	–	Russia	Yuan and Zhao 2024
Xylodon subtropicus	LWZ 20180510-24	MT319541	MT319308	China	Luo et al. 2022
Xylodon taiwanianus	CBS 125875	MH864080	MH875537	New Zealand	Vu et al. 2018
Xylodon tropicus	CLZhao 3351*	OL619261	OL619269	China	Qu et al. 2022
Xylodon ussuriensis	KUN 1989*	NR166241	–	America	Yuan and Zhao 2024
Xylodon verecundus	KHL 12261	DQ873642	DQ873643	Sweden	Larsson et al. 2006
Xylodon victoriensis	LWZ 20180510-29	MT319487	MT319228	Australia	Luo et al. 2022
Xylodon wenshanensis	CLZhao 15729*	OM338097	–	China	Luo et al. 2022
Xylodon wenshanensis	CLZhao 10790	OM338095	–	China	Luo et al. 2022
Xylodon wenshanensis	CLZhao 15782	OM338098	–	China	Luo et al. 2022
Xylodon wenshanensis	CLZhao 15718	OM338096	–	China	Luo et al. 2022
Xylodon xinpingensis	CLZhao 11224	MW394662	MW394654	China	Ma and Zhao 2021
Xylodon xinpingensis	CLZhao 9174*	MW394657	–	China	Ma and Zhao 2021
Xylodon yarraensis	LWZ 20180510-5	MT319639	MT319378	Australia	Luo et al. 2022
Xylodon yunnanensis	LWZ 20180922-47	MT319660	–	China	Wang et al. 2021

settings, and statistical support values were obtained using nonparametric bootstrapping with 1,000 replicates. Bayesian inference (BI) analysis based on the dataset was performed using MrBayes v.3.2.6 (Ronquist and Huelsenbeck 2003). The best substitution model for the dataset was selected by ModelFinder using a Bayesian information criterion, and the model was used for Bayesian analysis (Kalyaanamoorthy et al. 2017). Four Markov chains were run from random starting trees. Trees were sampled every 1.00th generation. The first 25% of sampled trees were discarded as burn-in, whereas other trees were used to construct a 50% majority consensus tree and for calculating Bayesian posterior probabilities (BPPs).

The branches of the consensus tree that received bootstrap support for ML were greater than or equal to 70%, and Bayesian posterior probabilities were greater than or equal to 0.95, respectively.

Results

BI analysis yielded a similar topology to MP and ML analysis; thus, the MP tree is provided (Figs 1–6). Branches that received bootstrap support for ML (ML-BS) and BI (BPP) greater than or equal to 70% (MP-BS and ML-BS) and 0.95 (BPP) were considered as significantly supported, respectively.

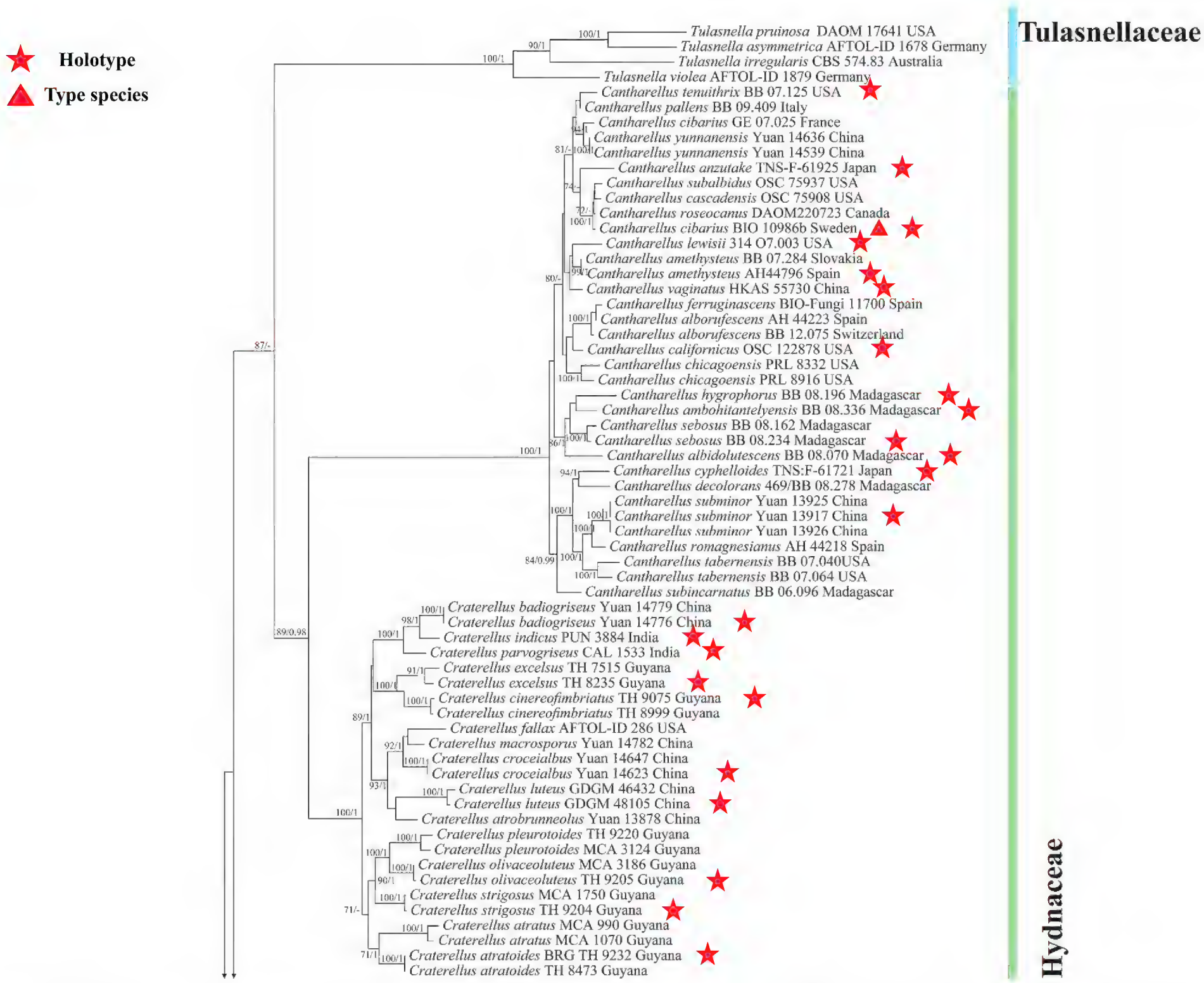
Holotype
Type species
Tulasnellaceae
Hydnaceae
Tulasnella pruinosa DAOM 17641 USA
Tulasnella asymmetrica AFTOL-ID 1678 Germany
Tulasnella irregularis CBS 574.83 Australia
Tulasnella violea AFTOL-ID 1879 Germany
Cantharellus tenuithrix BB 07.125 USA
Cantharellus pallens BB 09.409 Italy
Cantharellus cibarius GE 07.025 France
Cantharellus yunnanensis Yuan 14636 China
Cantharellus yunnanensis Yuan 14539 China
Cantharellus anzutake TNS-F-61925 Japan
Cantharellus subalbidus OSC 75937 USA
Cantharellus cascadensis OSC 75908 USA
Cantharellus roseocanus DAOM220723 Canada
Cantharellus cibarius BIO 10986b Sweden
Cantharellus lewisii 314 O7.003 USA
Cantharellus amethysteus BB 07.284 Slovakia
Cantharellus amethysteus AH44796 Spain
Cantharellus vaginatus HKAS 55730 China
Cantharellus ferruginascens BIO-Fungi 11700 Spain
Cantharellus alborufescens AH 44223 Spain
Cantharellus alborufescens BB 12.075 Switzerland
Cantharellus californicus OSC 122878 USA
Cantharellus chicagoensis PRL 8332 USA
Cantharellus chicagoensis PRL 8916 USA
Cantharellus hygrophorus BB 08.196 Madagascar
Cantharellus ambohitantelyensis BB 08.336 Madagascar
Cantharellus sebosus BB 08.162 Madagascar
Cantharellus sebosus BB 08.234 Madagascar
Cantharellus albidolutescens BB 08.070 Madagascar
Cantharellus cyphelloides TNS:F-61721 Japan
Cantharellus decolorans 469/BB 08.278 Madagascar
Cantharellus subminor Yuan 13925 China
Cantharellus subminor Yuan 13917 China
Cantharellus subminor Yuan 13926 China
Cantharellus romagnesianus AH 44218 Spain
Cantharellus tabernensis BB 07.040USA
Cantharellus tabernensis BB 07.064 USA
Cantharellus subincarnatus BB 06.096 Madagascar
Craterellus badiogriseus Yuan 14779 China
Craterellus badiogriseus Yuan 14776 China
Craterellus indicus PUN 3884 India
Craterellus parvogriseus CAL 1533 India
Craterellus excelsus TH 7515 Guyana
Craterellus excelsus TH 8235 Guyana
Craterellus cinereofimbriatus TH 9075 Guyana
Craterellus cinereofimbriatus TH 8999 Guyana
Craterellus fallax AFTOL-ID 286 USA
Craterellus macrosporus Yuan 14782 China
Craterellus croceialbus Yuan 14647 China
Craterellus croceialbus Yuan 14623 China
Craterellus luteus GDGM 46432 China
Craterellus luteus GDGM 48105 China
Craterellus atrobrunneolus Yuan 13878 China
Craterellus pleurotoides TH 9220 Guyana
Craterellus pleurotoides MCA 3124 Guyana
Craterellus olivaceoluteus MCA 3186 Guyana
Craterellus olivaceoluteus TH 9205 Guyana
Craterellus strigosus MCA 1750 Guyana
Craterellus strigosus TH 9204 Guyana
Craterellus atratus MCA 990 Guyana
Craterellus atratus MCA 1070 Guyana
Craterellus atratoides BRG TH 9232 Guyana
Craterellus atratoides TH 8473 Guyana

Figure 1. Phylogeny of species in Cantharellales generated by maximum likelihood based on ITS+nLSU sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

The phylogeny of Cantharellales

The ITS and nLSU dataset contained sequences from 135 fungal specimens representing 97 Cantharellales taxa. The average SD of split frequencies in BI analyses is 0.013339 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 725. The phylogenetic tree (Fig. 1) reveals that the Cantharellales new species were grouped into the genus *Botryobasidium* (Botryobasidiaceae).

The phylogeny of *Botryobasidium*

The ITS dataset contained sequences from 39 fungal specimens representing 22 *Botryobasidium* taxa. The average SD of split frequencies in BI analyses is 0.006652 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 1700.5. The phylogenetic tree (Fig. 2) reveals that the new species groups with three taxa, *Botryobasidium intertextum* (Schwein.) Jülich & Stalper, *B. leptocystidiatum* L.J. Zhou & H.S. Yuan, and *B. subcoronatum*.

Sistotrema confluens PV174 Czechia
Sistotrema confluens FCUG298 USA
Sistotrema subconfluens Dai 12577 China
Hydnum magnorufescens 161209 Slovenia
Hydnum subrufescens F1188749 USA
Hydnum berkeleyanum HKAS 77834 China
Hydnum berkeleyanum CAL 1656 India
Hydnum berkeleyanum Wei 10375 China
Hydnum ventricosum Yuan 14536 China
Hydnum tangerinum Wei 10245 China
Hydnum jussii Yuan 14009 China
Hydnum jussii Yuan 14008 China
Hydnum pallidocroceum Yuan 14017 China
Hydnum pallidocroceum Yuan 14023 China
Hydnum longibasidium Wei 10383 China
Hydnum longibasidium Wei 10367 China
Hydnum ellipsosporum FD 3281 Switzerland
Hydnum subolympicum F1188765 USA
Hydnum sphaericum Wei 10243 China
Hydnum minum Wei 10252 China
Hydnum minum N.K.Zeng2819 China
Hydnum minum Wei 10260 China
Hydnum brevispinum Wei 10214 China
Hydnum tenuistipitum Wei 10410 China
Hydnum flabellatum Yuan 14708 China
Hydnum pallidomarginatum Yuan 13940a China
Hydnum pallidomarginatum Yuan 13928a China
Hydnum cremeoalbum HKAS 92345 China
Hydnum albomagnum Wei 10247 China
Hydnum albomagnum Wei 10194 China
Hydnum albomagnum AFTOL-ID 471 USA
Hydnum flavidocanum Yuan 13900a China
Hydnum flavidocanum Yuan 13903a China
Clavulina cinereoglebosa TH8561 Guyana
Clavulina sp. MB03 034 USA
Clavulina cf. cristata MES426 China
Clavulina cristata JKU8 USA USA
Clavulina cerebriformis MCA 4022 Guyana
Rogersiomyces malaysianus LE-BIN 3507-10 Vietnam
Burgella lutea Etayo 27623 Bolivia
Multiclavula mucida TUB 011734 Germany
Multiclavula corynoides Lutzoni 930804_2 USA
Multiclavula vernalis Lutzoni 930806_1 USA
Multiclavula petricola 356 ex Japan
Neoburgoa freyi LF1256 Switzerland
Neoburgoa freyi JL596_16 Switzerland
Sistotremella perpusilla CBS 126048 USA
Bryoclavula phycophila TNS F-79667 Japan
Bryoclavula phycophila S-287-FB3 Japan
Minimedusa obcoronata CBS 120605 Thailand
Minimedusa polyspora CBS 113.16 USA
Burgoa verzuoliana CBS 131.38 Japan
Botryobasidium conspersum AFTOL-ID 1766 USA
Botryobasidium yunnanense CLZhao 24877 China
Botrybasidium gossypirubiginosum CLZhao 26052 China
Botryobasidium indicum AMH 10054 India
Botryobasidium robustius CBS 945.69 Czech Republic
Botryobasidium incanum CLZhao 26697 China
Botryobasidium subcoronatum AFTOL 614 USA
Botryobasidium daweishanensis CLZhao 40062 China
Botryobasidium simile GEL2348 Canada
Ceratorhiza hydrophila E14504F Ecuador
Rhizoctonia solani BRS 17 India
Ceratobasidium sp. CAG 6 USA
Ceratobasidium globisporum CBS 569.83 Australia
Oliveonia subfibrillosa TH 2018074 Finland
Oliveonia subfibrillosa TH 2018179 Finland
Oliveonia subfibrillosa VS 9048 Russia
Oliveonia subfibrillosa VS 9053 Russia
Trichosporon insectorum CBS 10422 Panama
Holtermanniella wattica CBS 9496 Antarctica
Dacrymyces australis CBS 196.63 Netherlands
0.6
Botryobasidiaceae
Ceratobasidiaceae
Oliveoniaceae
Tremellomycetes
Outgroup

Figure 1. Continued.

The phylogeny of Hymenochaetales

The ITS dataset contained sequences from 239 fungal specimens representing 196 Hymenochaetales taxa. The average SD of split frequencies in BI analyses is 0.013469 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 671.5. The phylogenetic tree (Fig. 3) reveals the four new Hymenochaetales species grouped into Hymenochaetaceae, Hyphodontiaceae, and Schizoporaceae.

Figure 2. Phylogeny of species in *Botryobasidium* generated by maximum likelihood based on ITS sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

The phylogeny of *Inonotus*

The ITS dataset contained sequences from 49 fungal specimens representing 26 *Inonotus* taxa. The average SD of split frequencies in BI analyses is 0.004227 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 2018.5. The phylogenetic tree (Fig. 4) reveals that the new species is closely related to *Inonotus radiatus* (Sowerby) P. Karst.

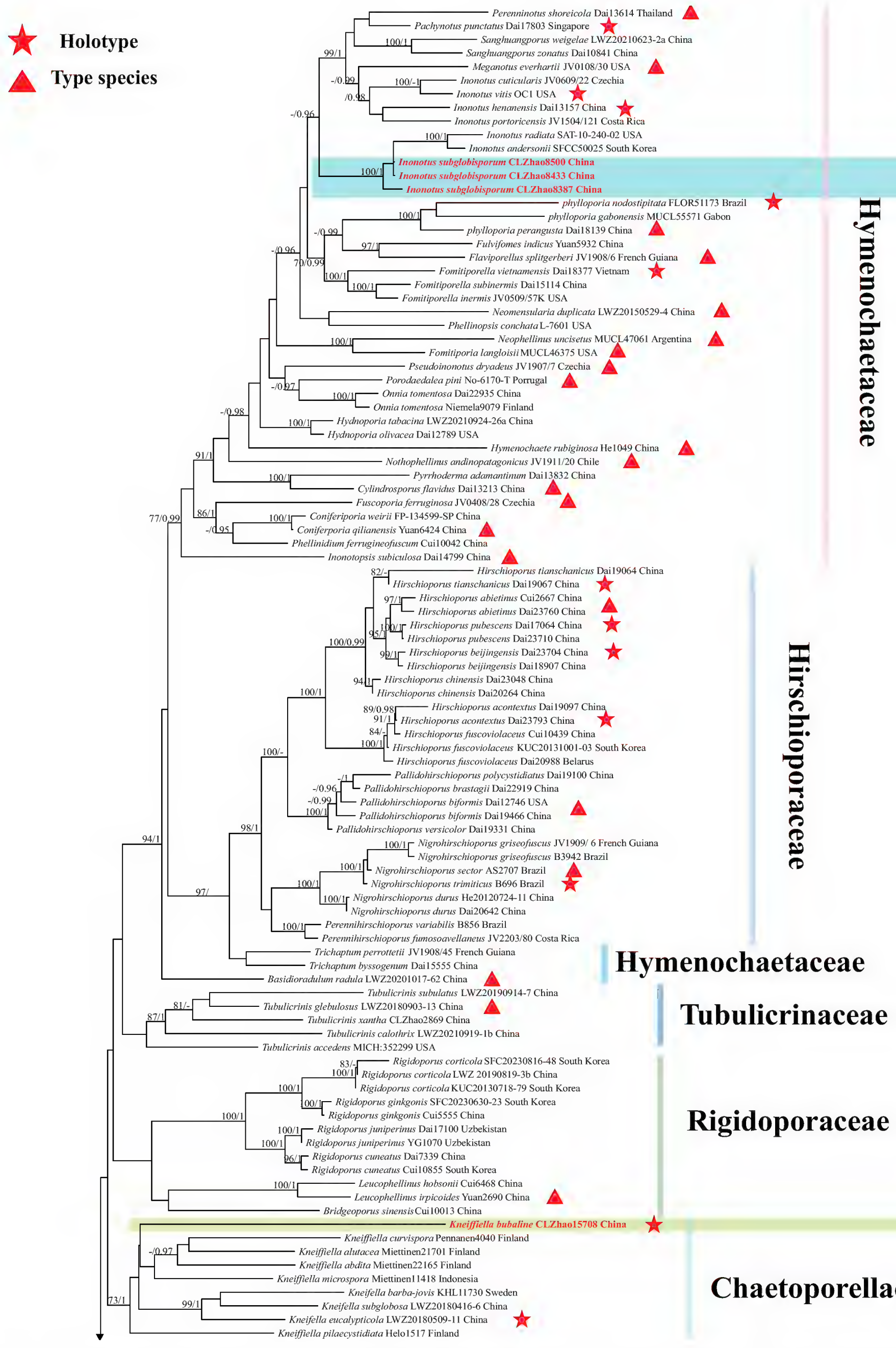

Figure 3. Phylogeny of species in Hymenochaetales generated by maximum likelihood based on ITS+nLSU sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

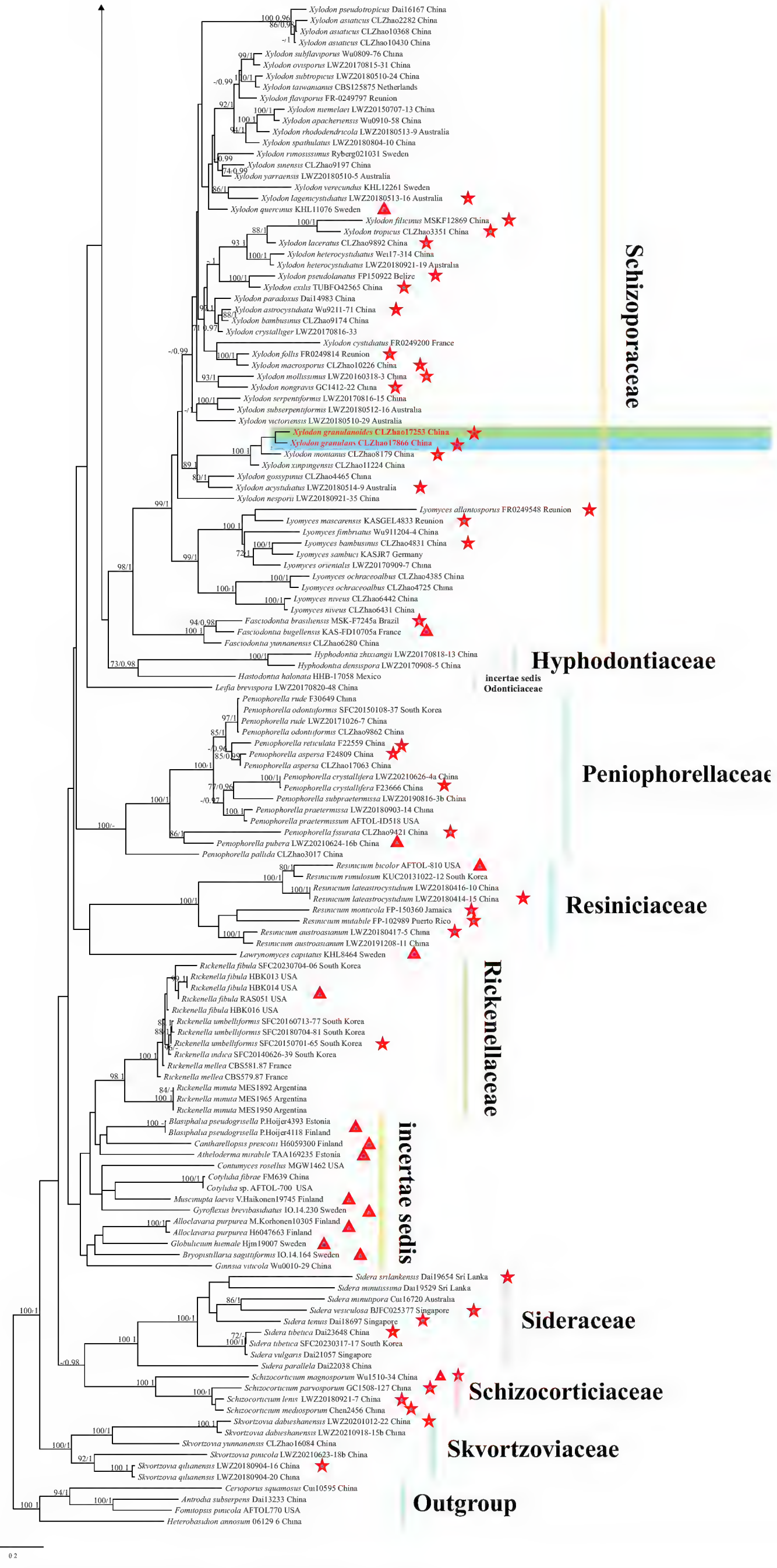

Figure 3. Continued.

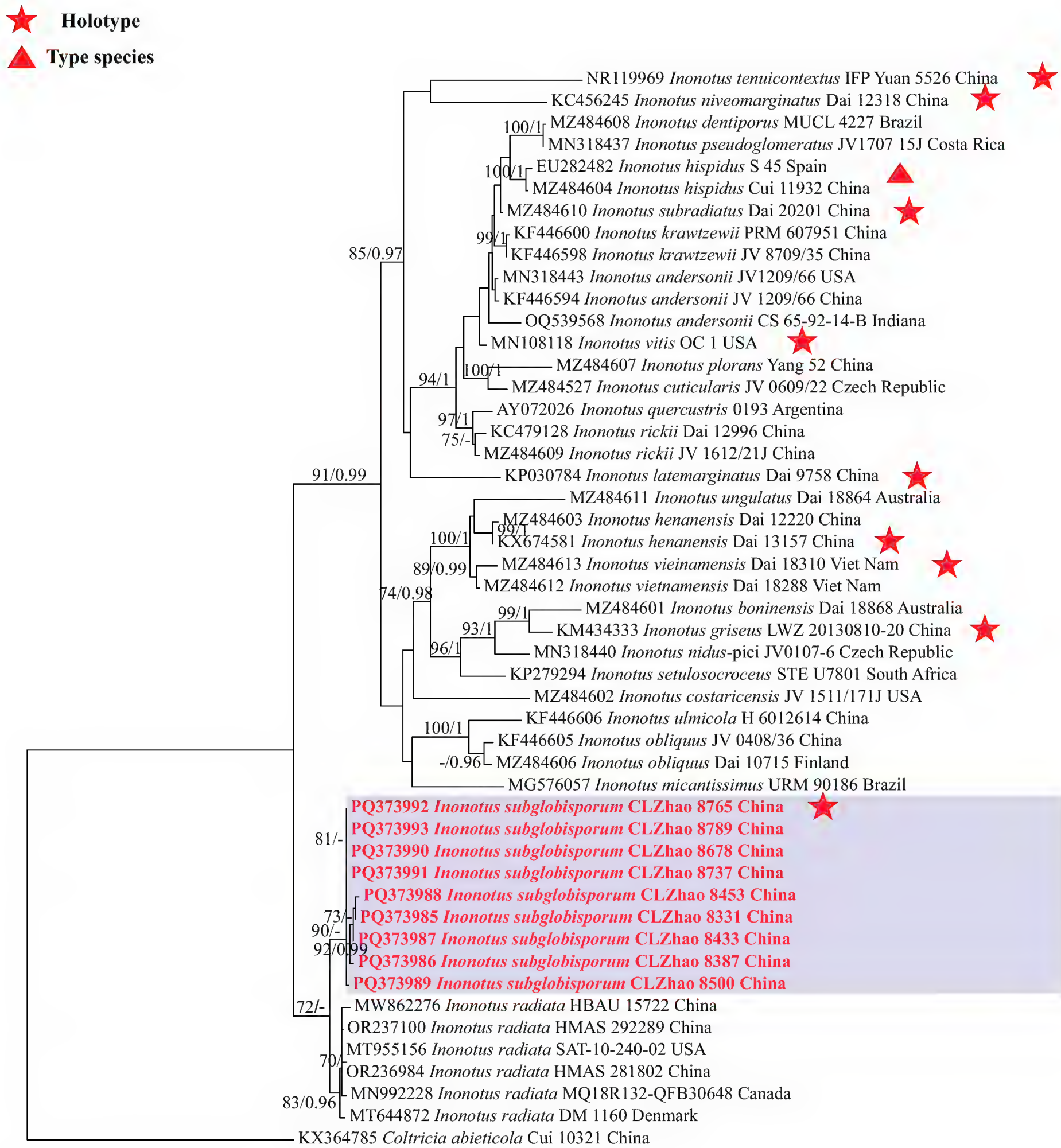
Holotype
Type species
NR119969 Inonotus tenuicontextus IFP Yuan 5526 China
KC456245 Inonotus niveomarginatus Dai 12318 China
MZ484608 Inonotus dentiporus MUCL 4227 Brazil
MN318437 Inonotus pseudoglomeratus JV1707 15J Costa Rica
EU282482 Inonotus hispidus S 45 Spain
MZ484604 Inonotus hispidus Cui 11932 China
MZ484610 Inonotus subradiatus Dai 20201 China
KF446600 Inonotus krawtzewii PRM 607951 China
KF446598 Inonotus krawtzewii JV 8709/35 China
MN318443 Inonotus andersonii JV1209/66 USA
KF446594 Inonotus andersonii JV 1209/66 China
OQ539568 Inonotus andersonii CS 65-92-14-B Indiana
MN108118 Inonotus vitis OC 1 USA
MZ484607 Inonotus plorans Yang 52 China
MZ484527 Inonotus cuticularis JV 0609/22 Czech Republic
AY072026 Inonotus quercustris 0193 Argentina
KC479128 Inonotus rickii Dai 12996 China
MZ484609 Inonotus rickii JV 1612/21J China
KP030784 Inonotus latemarginatus Dai 9758 China
MZ484611 Inonotus ungulatus Dai 18864 Australia
MZ484603 Inonotus henanensis Dai 12220 China
KX674581 Inonotus henanensis Dai 13157 China
MZ484613 Inonotus vieinamensis Dai 18310 Viet Nam
MZ484612 Inonotus vietnamensis Dai 18288 Viet Nam
MZ484601 Inonotus boninensis Dai 18868 Australia
KM434333 Inonotus griseus LWZ 20130810-20 China
MN318440 Inonotus nidus-pici JV0107-6 Czech Republic
KP279294 Inonotus setulosocroceus STE U7801 South Africa
MZ484602 Inonotus costaricensis JV 1511/171J USA
KF446606 Inonotus ulmicola H 6012614 China
KF446605 Inonotus obliquus JV 0408/36 China
MZ484606 Inonotus obliquus Dai 10715 Finland
MG576057 Inonotus micantissimus URM 90186 Brazil
PQ373992 Inonotus subglobisporum CLZhao 8765 China
PQ373993 Inonotus subglobisporum CLZhao 8789 China
PQ373990 Inonotus subglobisporum CLZhao 8678 China
PQ373991 Inonotus subglobisporum CLZhao 8737 China
PQ373988 Inonotus subglobisporum CLZhao 8453 China
PQ373985 Inonotus subglobisporum CLZhao 8331 China
PQ373987 Inonotus subglobisporum CLZhao 8433 China
PQ373986 Inonotus subglobisporum CLZhao 8387 China
PQ373989 Inonotus subglobisporum CLZhao 8500 China
MW862276 Inonotus radiata HBAU 15722 China
OR237100 Inonotus radiata HMAS 292289 China
MT955156 Inonotus radiata SAT-10-240-02 USA
OR236984 Inonotus radiata HMAS 281802 China
MN992228 Inonotus radiata MQ18R132-QFB30648 Canada
MT644872 Inonotus radiata DM 1160 Denmark
KX364785 Coltricia abieticola Cui 10321 China
85/0.97
100/1
100/1
99/1
94/1
100/1
97/1
75/-
91/0.99
100/1
99/1
89/0.99
74/0.98
99/1
93/1
96/1
100/1
-/0.96
81/-
73/-
90/-
92/0.99
72/-
70/-
83/0.96
0.2

Figure 4. Phylogeny of species in *Inonotus* generated by maximum likelihood based on ITS sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

The phylogeny of *Kneiffiella*

The ITS dataset contained sequences from 26 fungal specimens representing 21 *Kneiffiella* taxa. The average SD of split frequencies in BI analyses is 0.007515 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 4107.5. The phylogenetic tree (Fig. 5) reveals that the new species is closely related to *Kneiffiella subalutacea* (P. Karst.) Jülich & Stalpers.

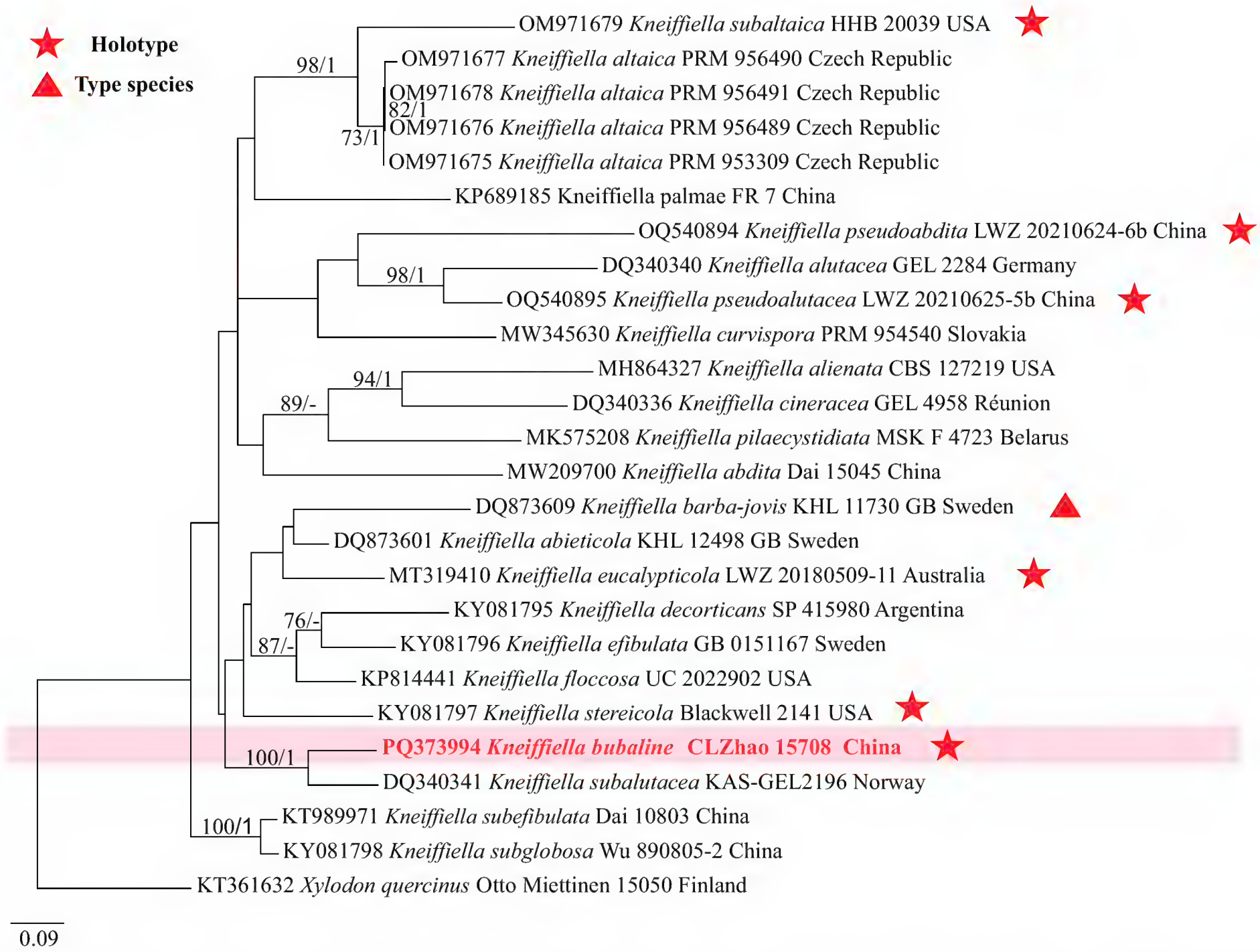
Holotype
Type species
OM971679 Kneiffiella subaltaica HHB 20039 USA
OM971677 Kneiffiella altaica PRM 956490 Czech Republic
OM971678 Kneiffiella altaica PRM 956491 Czech Republic
OM971676 Kneiffiella altaica PRM 956489 Czech Republic
OM971675 Kneiffiella altaica PRM 953309 Czech Republic
KP689185 Kneiffiella palmae FR 7 China
OQ540894 Kneiffiella pseudoabdita LWZ 20210624-6b China
DQ340340 Kneiffiella alutacea GEL 2284 Germany
OQ540895 Kneiffiella pseudoalutacea LWZ 20210625-5b China
MW345630 Kneiffiella curvispora PRM 954540 Slovakia
MH864327 Kneiffiella alienata CBS 127219 USA
DQ340336 Kneiffiella cineracea GEL 4958 Réunion
MK575208 Kneiffiella pilaecystidiata MSK F 4723 Belarus
MW209700 Kneiffiella abdita Dai 15045 China
DQ873609 Kneiffiella barba-jovis KHL 11730 GB Sweden
DQ873601 Kneiffiella abieticola KHL 12498 GB Sweden
MT319410 Kneiffiella eucalypticola LWZ 20180509-11 Australia
KY081795 Kneiffiella decorticans SP 415980 Argentina
KY081796 Kneiffiella efibulata GB 0151167 Sweden
KP814441 Kneiffiella floccosa UC 2022902 USA
KY081797 Kneiffiella stereicola Blackwell 2141 USA
PQ373994 Kneiffiella bubaline CLZhao 15708 China
DQ340341 Kneiffiella subalutacea KAS-GEL2196 Norway
KT989971 Kneiffiella subefibulata Dai 10803 China
KY081798 Kneiffiella subglobosa Wu 890805-2 China
KT361632 Xylodon quercinus Otto Miettinen 15050 Finland
98/1
82/1
73/1
98/1
94/1
89/-
76/-
87/-
100/1
100/1
0.09

Figure 5. Phylogeny of species in *Kneiffiella* generated by maximum likelihood based on ITS sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

The phylogeny of *Xylodon*

The ITS dataset contained sequences from 149 fungal specimens representing 94 *Xylodon* taxa, 15 *Hyphodontia* J. Eriksss taxa, five *Lyomyces* P. Karst taxa, and four *Kneiffiella* taxa. The average SD of split frequencies in BI analyses is 0.020943 (BI), and the effective sample size (ESS) for Bayesian analysis across the two runs is double the average ESS (avg ESS) = 1031.5. The phylogenetic tree (Fig. 6) reveals that the new species has a close relationship with *Xylodon bambusinus* C.L. Zhao & X. Ma, *X. fissuratus* C.L. Zhao, *X. subclavatus* (Yurchenko, H.X. Xiong and Sheng H. Wu) Riebesehl, Yurch. & Langer, *X. montanus* C.L. Zhao and *X. wenshanensis* K.Y. Luo & C.L. Zhao. Additionally, *Xylodon granulanoides* and *X. granulans* clustered together.

Taxonomy

***Botryobasidium daweishanense* J.L. Zhang, H.M. Zhou & C.L. Zhao, sp. nov.**
MycoBank No: 856337
Figs 7, 8

Diagnosis. *Botryobasidium daweishanense* differs from *B. subcoronatum* by its araneose hymenial surface, smaller basidia, fusiform, cyanophilous, and wider basidiospores.

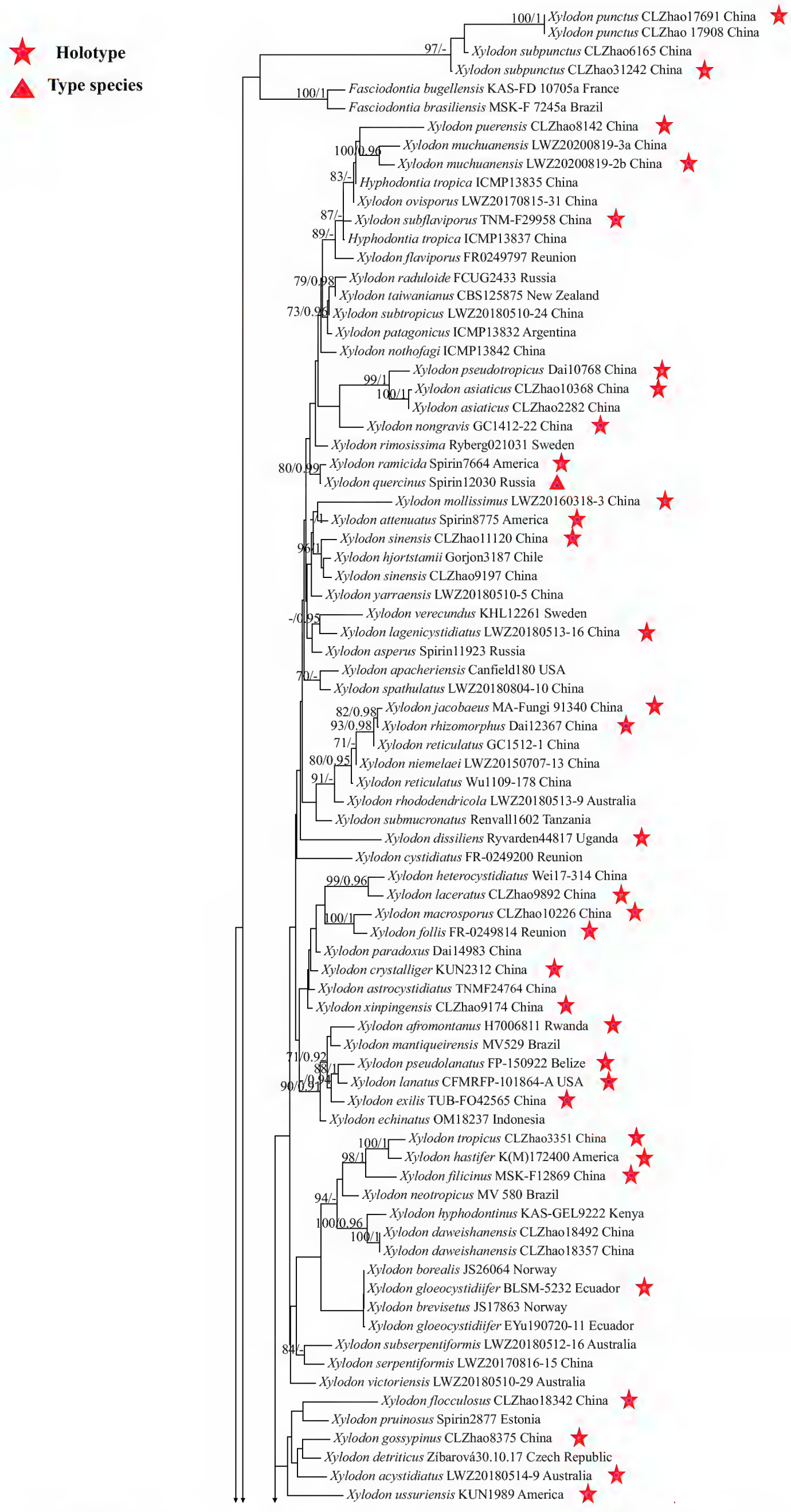
Holotype
Type species
100/1 Xylodon punctus CLZhao17691 China
Xylodon punctus CLZhao 17908 China
97/- Xylodon subpunctus CLZhao6165 China
Xylodon subpunctus CLZhao31242 China
100/1 Fasciodontia bugellensis KAS-FD 10705a France
Fasciodontia brasiliensis MSK-F 7245a Brazil
Xylodon puerensis CLZhao8142 China
100/0.96 Xylodon muchuanensis LWZ20200819-3a China
Xylodon muchuanensis LWZ20200819-2b China
83/- Hyphodontia tropica ICMP13835 China
Xylodon ovisporus LWZ20170815-31 China
87/- Xylodon subflaviporus TNM-F29958 China
89/- Hyphodontia tropica ICMP13837 China
Xylodon flaviporus FR0249797 Reunion
79/0.98 Xylodon raduloide FCUG2433 Russia
Xylodon taiwanianus CBS125875 New Zealand
73/0.96 Xylodon subtropicus LWZ20180510-24 China
Xylodon patagonicus ICMP13832 Argentina
Xylodon nothofagi ICMP13842 China
Xylodon pseudotropicus Dai10768 China
99/1 Xylodon asiaticus CLZhao10368 China
100/1 Xylodon asiaticus CLZhao2282 China
Xylodon nongravis GC1412-22 China
Xylodon rimosissima Ryberg021031 Sweden
80/0.99 Xylodon ramicida Spirin7664 America
Xylodon quercinus Spirin12030 Russia
Xylodon mollissimus LWZ20160318-3 China
-/1 Xylodon attenuatus Spirin8775 America
Xylodon sinensis CLZhao11120 China
96/1 Xylodon hjortstamii Gorjon3187 Chile
Xylodon sinensis CLZhao9197 China
Xylodon yarraensis LWZ20180510-5 China
-/0.95 Xylodon verecundus KHL12261 Sweden
Xylodon lagenicystidiatus LWZ20180513-16 China
Xylodon asperus Spirin11923 Russia
70/- Xylodon apacheriensis Canfield180 USA
Xylodon spathulatus LWZ20180804-10 China
82/0.98 Xylodon jacobaeus MA-Fungi 91340 China
93/0.98 Xylodon rhizomorphus Dai12367 China
71/- Xylodon reticulatus GC1512-1 China
80/0.95 Xylodon niemelaei LWZ20150707-13 China
91/- Xylodon reticulatus Wu1109-178 China
Xylodon rhododendricola LWZ20180513-9 Australia
Xylodon submucronatus Renvall1602 Tanzania
Xylodon dissiliens Ryvarden44817 Uganda
Xylodon cystidiatus FR-0249200 Reunion
99/0.96 Xylodon heterocystidiatus Wei17-314 China
Xylodon laceratus CLZhao9892 China
100/1 Xylodon macrosporus CLZhao10226 China
Xylodon follis FR-0249814 Reunion
Xylodon paradoxus Dai14983 China
Xylodon crystalliger KUN2312 China
Xylodon astrocystidiatus TNMF24764 China
Xylodon xinpingensis CLZhao9174 China
Xylodon afromontanus H7006811 Rwanda
Xylodon mantiqueirensis MV529 Brazil
71/0.92 Xylodon pseudolanatus FP-150922 Belize
88/1 Xylodon lanatus CFMRFP-101864-A USA
-/0.94
90/0.91 Xylodon exilis TUB-FO42565 China
Xylodon echinatus OM18237 Indonesia
100/1 Xylodon tropicus CLZhao3351 China
98/1 Xylodon hastifer K(M)172400 America
Xylodon filicinus MSK-F12869 China
94/- Xylodon neotropicus MV 580 Brazil
100/0.96 Xylodon hyphodontinus KAS-GEL9222 Kenya
100/1 Xylodon daweishanensis CLZhao18492 China
Xylodon daweishanensis CLZhao18357 China
Xylodon borealis JS26064 Norway
Xylodon gloeocystidiifer BLSM-5232 Ecuador
Xylodon brevisetus JS17863 Norway
Xylodon gloeocystidiifer EYu190720-11 Ecuador
84/- Xylodon subserpentiformis LWZ20180512-16 Australia
Xylodon serpentiformis LWZ20170816-15 China
Xylodon victoriensis LWZ20180510-29 Australia
Xylodon flocculosus CLZhao18342 China
Xylodon pruinosus Spirin2877 Estonia
Xylodon gossypinus CLZhao8375 China
Xylodon detriticus Zíbarová30.10.17 Czech Republic
Xylodon acystidiatus LWZ20180514-9 Australia
Xylodon ussuriensis KUN1989 America

Figure 6. Phylogeny of species in *Xylodon* generated by maximum likelihood based on ITS sequence data. Branches are labeled with maximum likelihood bootstrap ≥ 70% and Bayesian posterior probabilities ≥ 0.95, respectively.

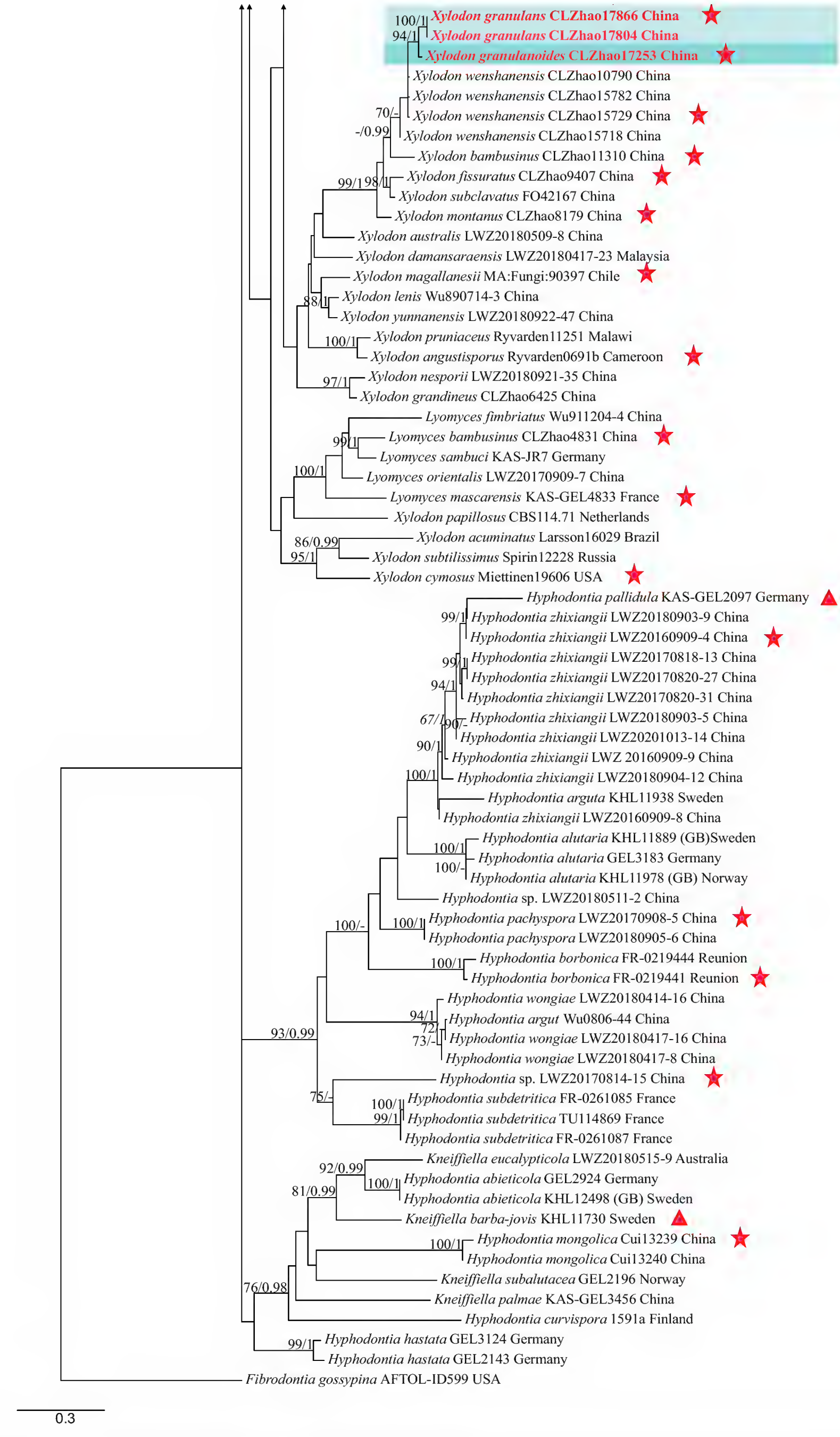

Figure 6. Continued.

Holotype. China • Yunnan Province, Honghe, Pingbian County, Daweishan National Nature Reserve, 28°42'N, 114°11'E, evel. 1356 m asl., on fallen angiosperm branch, 1 August 2019, CLZhao 40062 (SWFC).

Etymology. *Daweishanense* (Lat.) refers to the type location "Daweishan National Nature Reserve," China.

Description. *Basidiomata*. Annual, resupinate, coriaceous, without odor or taste when fresh, up to 1.6 cm long, 1.5 cm wide, and 100 μm thick. Hymenial surface araneose, cream when fresh, straw-yellow to yellowish when dry. Sterile margin thin, indistinct, slightly yellowish, up to 0.5 mm.

***Hyphal system*.** Monomitic; generative hyphae with clamp connections, hyaline, thin to slightly thick-walled, frequently branched, interwoven, 5.0–8.0 μm in diam, IKI–, CB+; tissues unchanged in KOH.

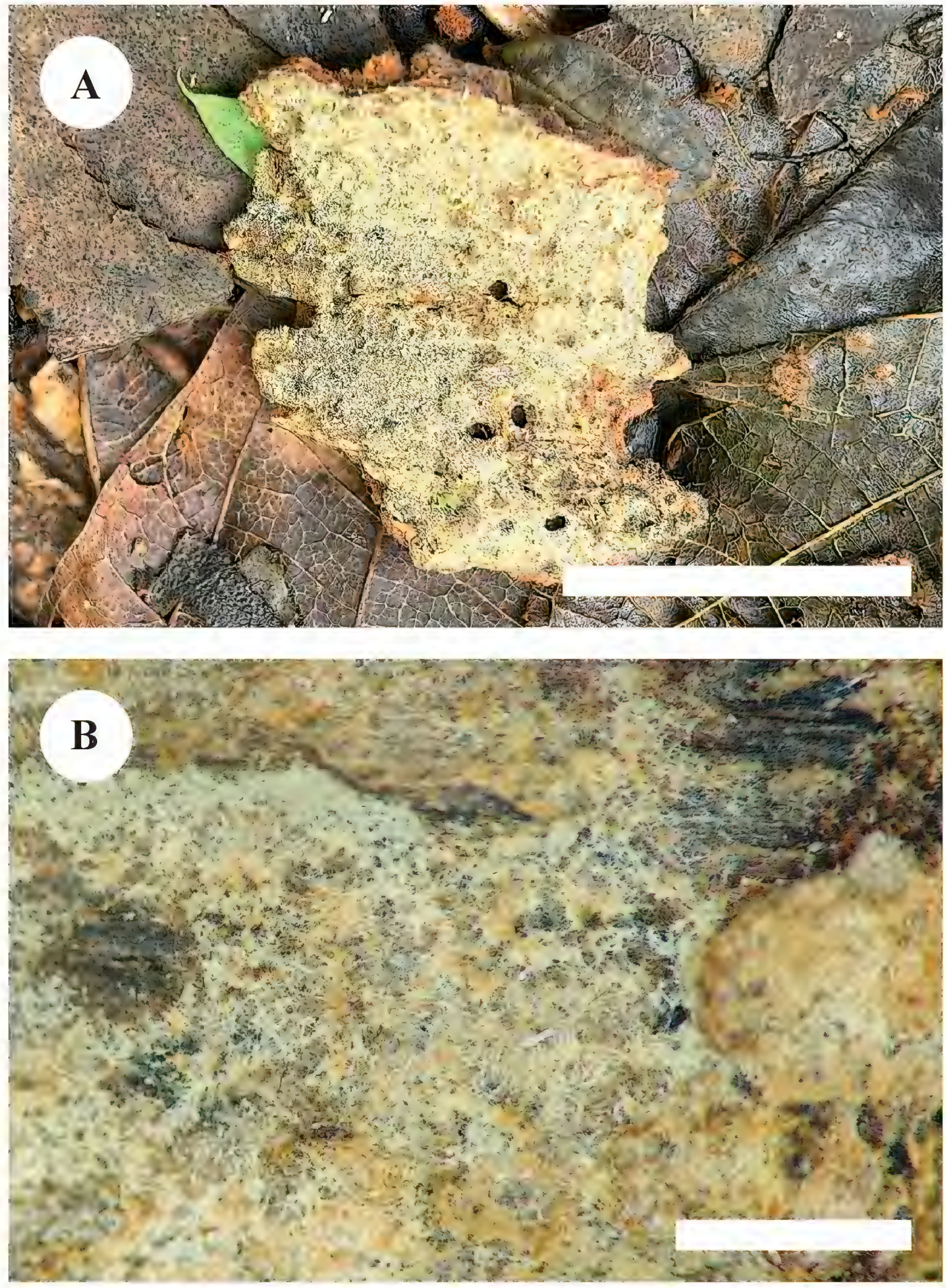

Figure 7. Basidiomata of *Botryobasidium daweishanense* (holotype, CLZhao 40062) **A** the front of the basidiomata **B** characteristic hymenophore. Scale bars: 1 cm (**A**); 1 mm (**B**).

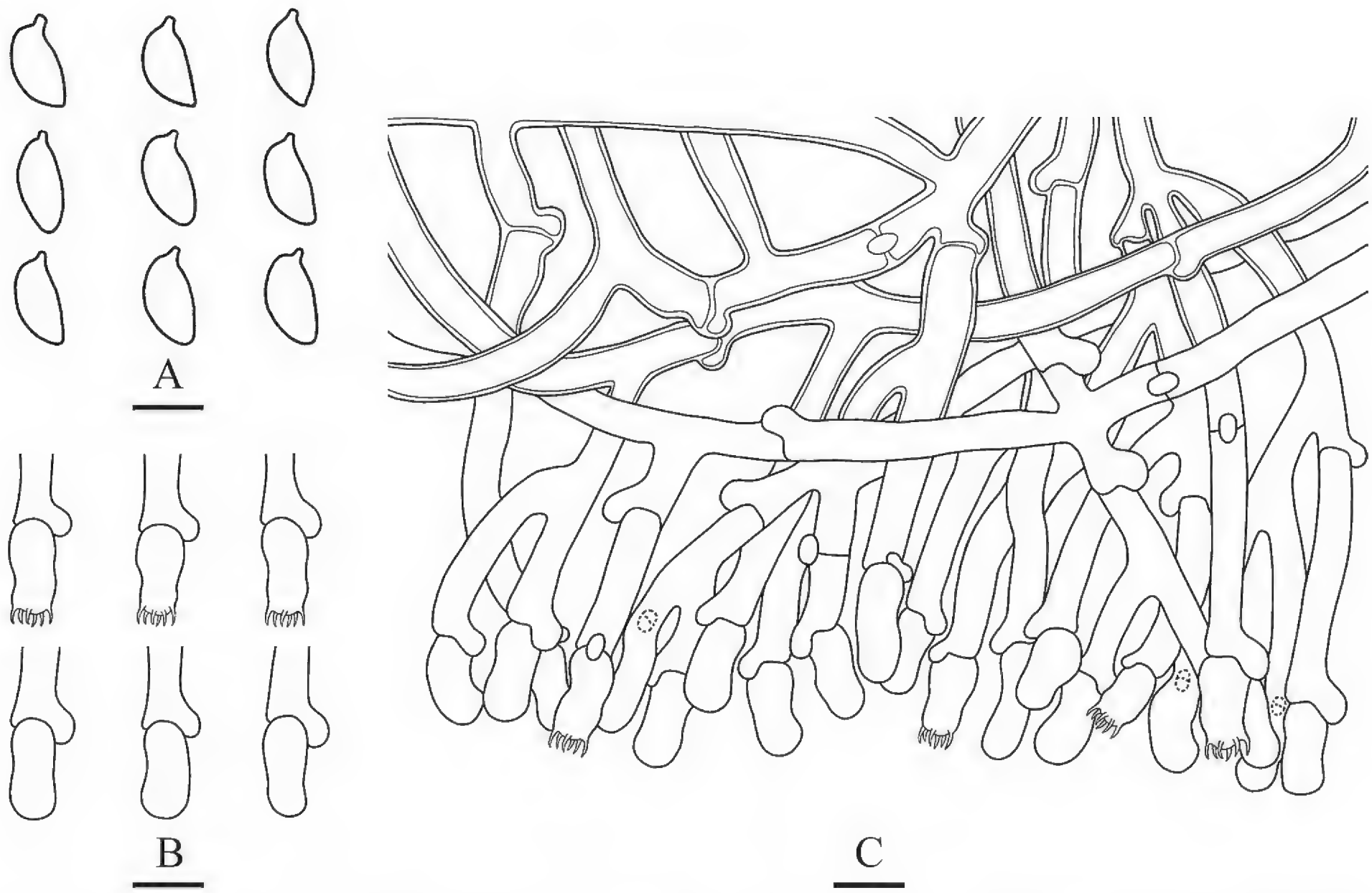

Figure 8. Microscopic structures of *Botryobasidium daweishanense* (holotype, CLZhao 40062) **A** basidiospores **B** basidia and basidioles **C** a section of hymenium. Scale bars: 5 μm (**A**); 10 μm (**B, C**); 10 × 100 oil.

***Hymenium*.** Cystidia and cystidoles absent. Basidia barred, slightly sinuous, with six short sterigmata and a basal clamp connection, 11.5–18.0 × 5.0–8.0 μm; basidioles dominant, in shape similar to basidia, but slightly smaller. ***Basidiospores*.** Fusiform, hyaline, thin-walled, smooth, IKI–, CB+, (6.0–)6.1–7.3 × (3.1–)3.3–3.9(–4.1) μm, L = 6.65 μm, W = 3.64 μm, Q = 1.81–1.85 (n = 60/2).

Additional specimens examined. China • Yunnan Province, Honghe, Pingbian County, Daweishan National Nature Reserve, 28°42'N, 114°11'E, evel. 1356 m asl., on fallen angiosperm branch, 1 August 2019, CLZhao 40061 (SWFC).

***Inonotus subglobisporum* J.L. Zhang, H.M. Zhou & C.L. Zhao, sp. nov.**

MycoBank No: 856340

Figs 9, 10

Diagnosis. *Inonotus subglobisporum* differs from *I. radiata* by its perennial basidiomata, laterally stipitate, polygon pores, tapered, dark brown, thick-walled setae, and subglobose, thick-walled, hyaline basidiospores.

Holotype. China • Yunnan Province, Puer, Jingdong County, Ailaoshan National Nature Reserve, 23°42'N, 101°52'E, evel. 2450 m asl., on fallen angiosperm trunk, 25 August 2018, CLZhao 8765 (SWFC).

Etymology. *Subglobisporum* (Lat.) refers to the subglobose basidiospores.

Description. *Basidiomata*. Perennial, laterally stipitate, solitary, without odor or taste when fresh. Pilei fan-shaped, cortical to cork, extend up to 1.3 cm long, 2.2 cm wide, and 6 mm thick in diam at the base. Pileal surface honey-yellow

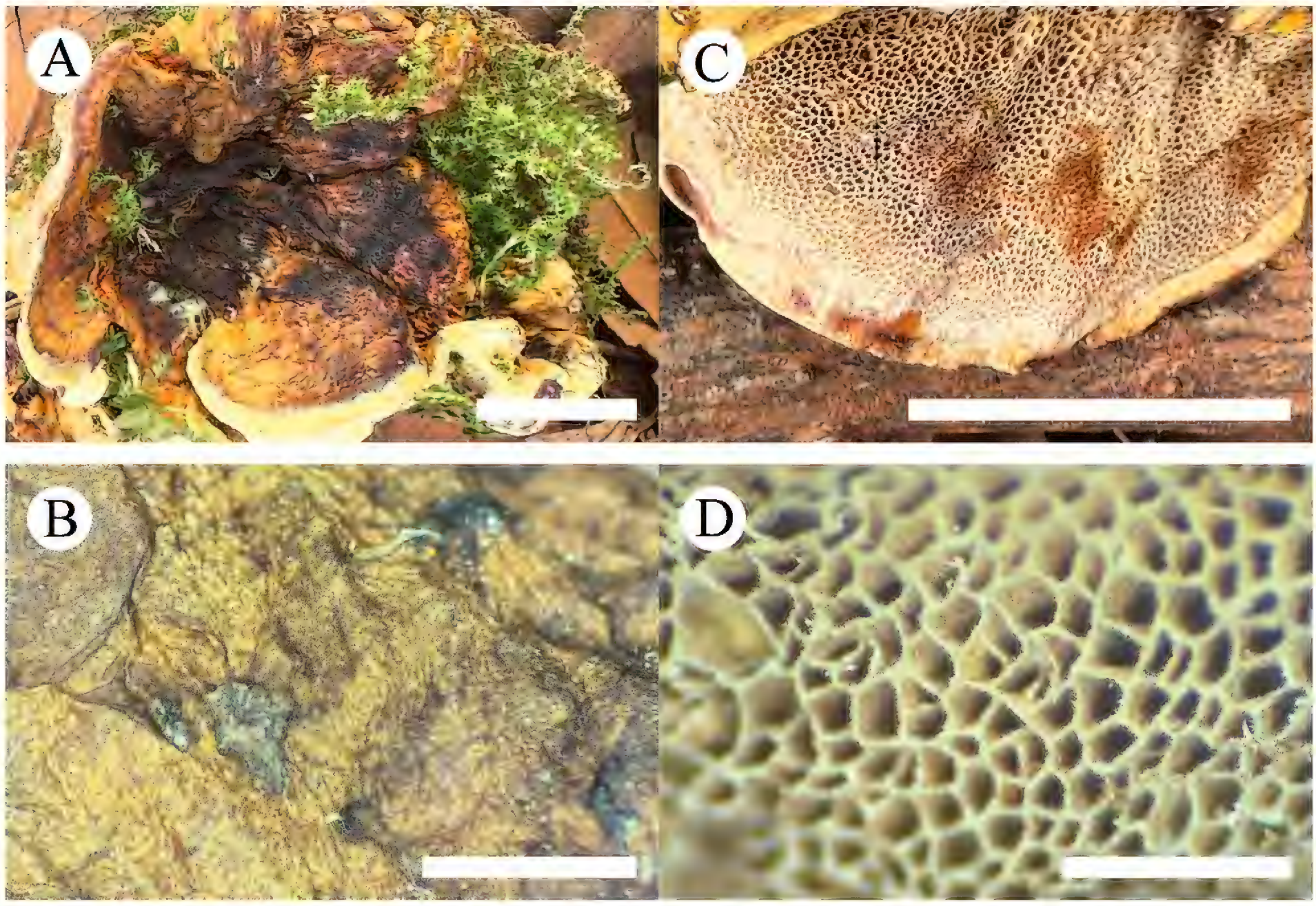

Figure 9. Basidiomata of *Inonotus subglobisporum* (holotype, CLZhao 8765) **A, B** the front of the basidiomata **C, D** characteristic hymenophore. Scale bars: 1 cm (**A, C**); 1 mm (**B, D**).

to fuscous when fresh, vinaceous brown to fuscous when dry. Pore surface cream, when fresh, becomes cream to fawn when dry; pores polygonal, 4–6 per mm. Context cinnamon-buff when dry, cork, up to 5 mm thick. Tubes cream to fawn when dry, cork, up to 1 mm long. Stipe with the same color as pores, up to 23 mm long and 15 mm in diameter when dry.

***Hyphal structure*.** Monomitic; generative hyphae, simple-septate, slightly thick-walled, frequently branched, interwoven. Generative hyphae in the tube frequent, brownish, slightly thick-walled, easily collapsing, 2.5–5.0 µm in diam. Generative hyphae in the context frequent, brown, slightly thick-walled, 3.0–7.0 µm in diam, IKI–, CB–; tissues brownish in KOH. ***Context*.** Setae numerous, tapered, dark brown, thick-walled, strongly encrusted in the surface, and almost entirely buried, 12.0–69.5 × 4.0–11.0 µm, cystidoles absent. Basidia clavate, with four short sterigmata and a basal simple-septate, 5.5–13.0 × 2.5–6.5 µm; basidioles in shape similar to basidia, but slightly smaller. ***Basidiospores*.** Subglobose, hyaline, thick-walled, smooth, IKI–, CB+, (3.5–)3.6–4.3(–4.4) × (2.6–)2.8–3.5(–3.6) µm, L = 3.99 µm, W = 3.20 µm, Q = 1.22–1.27 (n = 120/4).

Other specimens examined. China • Yunnan Province, Puer, Jingdong County, Ailaoshan National Nature Reserve, 23°42'N, 101°52'E, evel. 2450 m asl., on fallen angiosperm trunk, 23 August 2018, CLZhao 8331; CLZhao 8387; CLZhao 8433; CLZhao 8543; 24 August 2018, CLZhao 8500; 25 August 2018, CLZhao 8678; CLZhao 8737; CLZhao 8789 (SWFC).

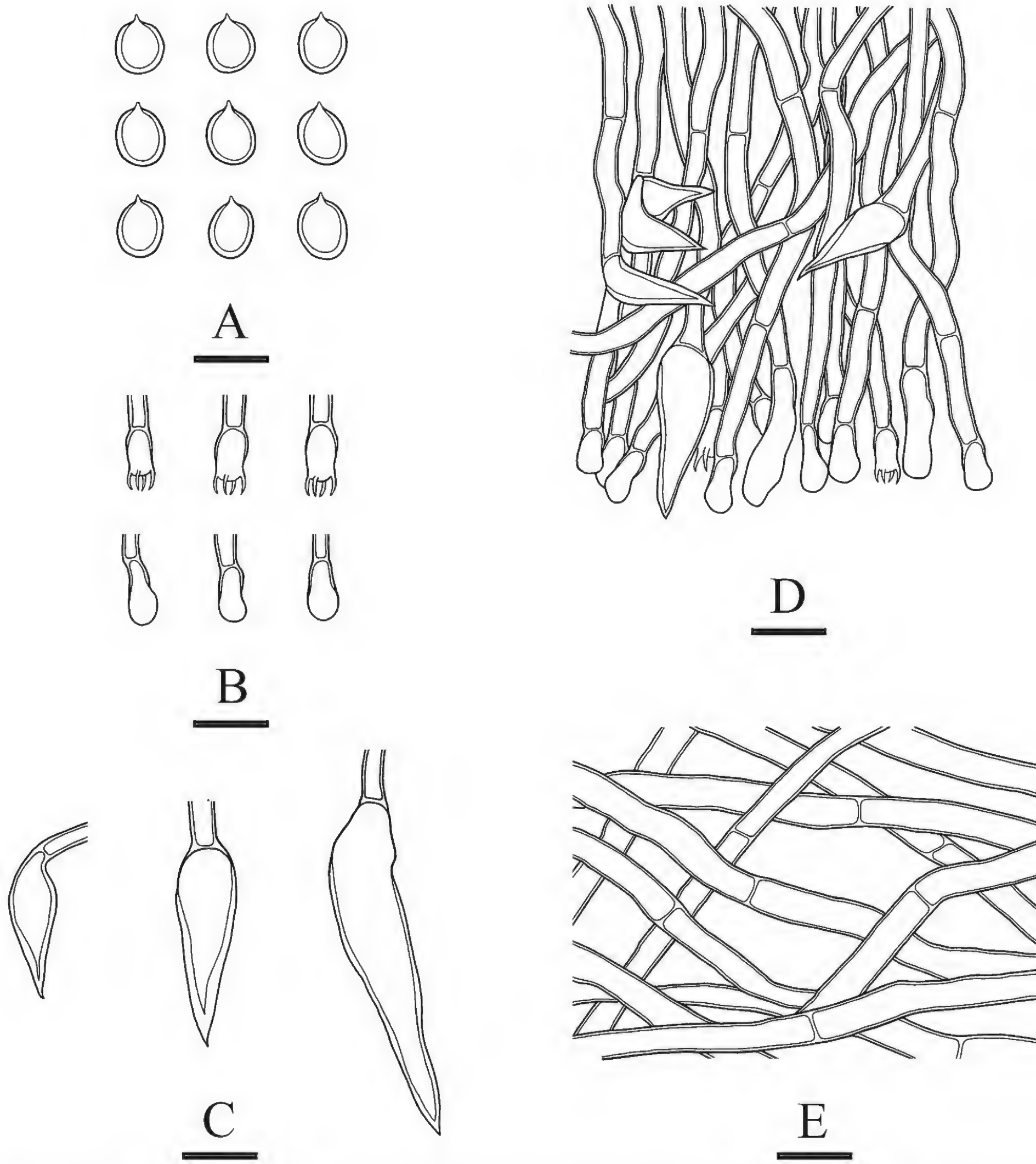

Figure 10. Microscopic structures of *Inonotus subglobisporum* (holotype, CLZhao 8765) **A** basidiospores **B** basidia and basidioles **C** setae **D** hymenium and hyphae from trama **E** hyphae from context. Scale bars: 5 µm (**A**); 10 µm (**B–E**); 10 × 100 oil.

Kneiffiella bubalina **J.L. Zhang, H.M. Zhou & C.L. Zhao, sp. nov.**

MycoBank No: 856342

Figs 11, 12

Diagnosis. *Kneiffiella bubalina* differs from *K. subalutacea* by its cream basidiomata and cylindrical to slightly allantoid basidiospores.

Figure 11. Basidiomata of *Kneiffiella bubalina* (holotype, CLZhao 15708) **A** the front of the basidiomata **B** characteristic hymenophore. Scale bars: 1 cm (**A**); 1 mm (**B**).

Holotype. China • Yunnan Province, Wenshan, Xichou County, Jiguanshan Forestry Park, 23°53'N, 104°82'E, evel. 1730 m asl., on fallen angiosperm branch, 22 July 2019, CLZhao 15708 (SWFC).

Etymology. *Bubalina* (Lat.) refers to its buff-colored hymenial surface.

Description. ***Basidiomata*.** Annual, resupinate, smooth, membranous, without odor or taste when fresh, up to 1.6 cm long, 1.1 cm wide, and 0.1–0.2 mm thick. Hymenial surface araneose, white to cream when fresh, buff when dry. Sterile margin thin, indistinct, slightly buff, up to 1 mm.

***Hyphal system*.** Monomitic; generative hyphae with clamp connections, slightly thick-walled, frequently branched, interwoven, IKI–, CB–, 2.5–3.5 µm in diam; tissues unchanged in KOH.

***Hymenium*.** Cystidia numerous, tubular, rising from subiculum with a basal clamp connection, hyaline, thick-walled except in the apical part, smooth,

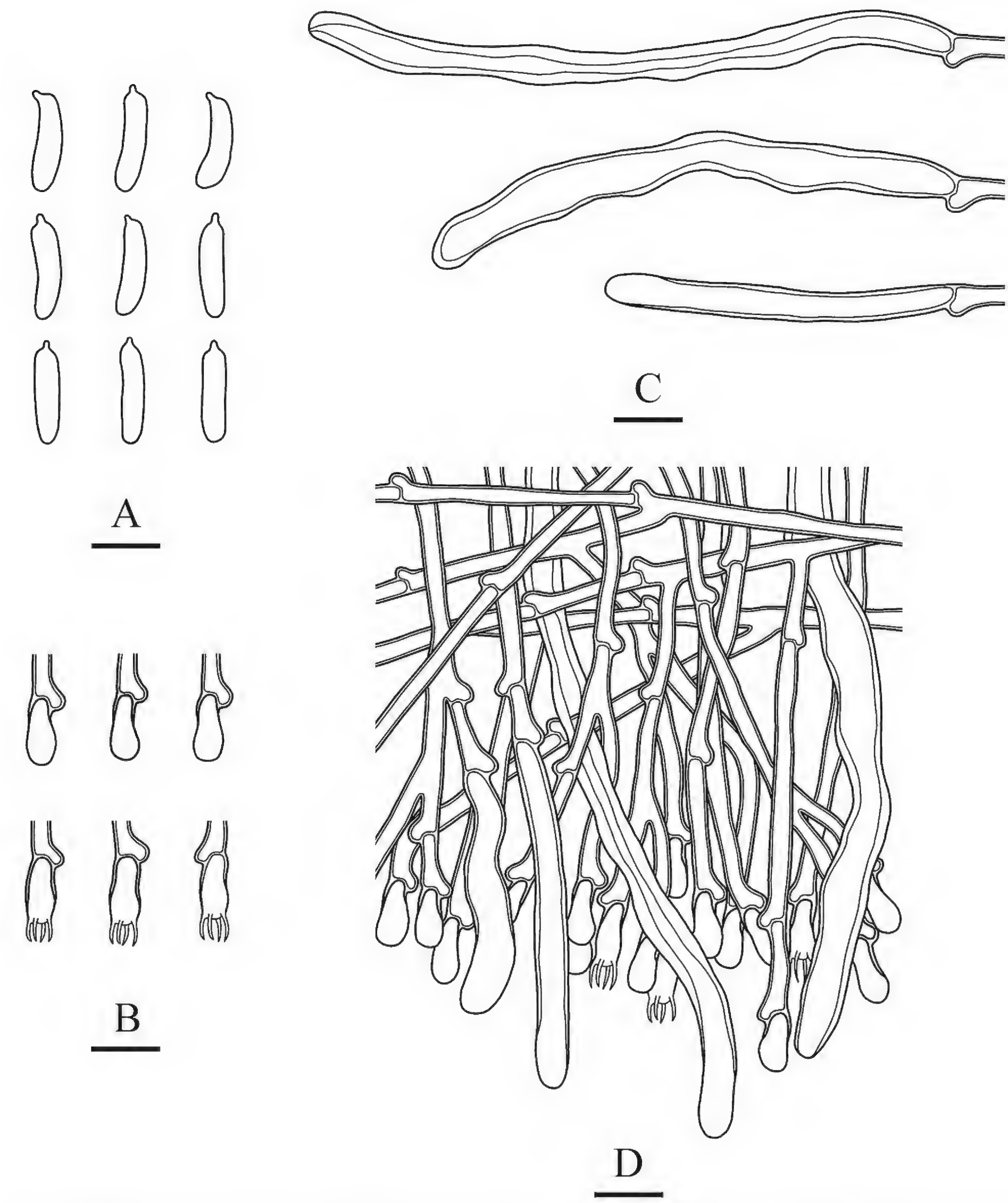

Figure 12. Microscopic structures of *Kneiffiella bubalina* (holotype, CLZhao 15708) **A** basidiospores **B** basidia and basidioles **C** cystidia **D** a section of hymenium. Scale bars: 5 μm (**A**); 10 μm (**B–D**); 10 × 100 oil.

103.5–162.5 × 6.0–8.0 μm; cystidioles absent. Basidia club-shaped, slight constriction in the middle part, with four sterigmata and a basal clamp connection, 10.0–14.0 × 4.5–5.0 μm; basidioles dominant, in shape similar to basidia, but slightly smaller. ***Basidiospores*.** Cylindrical to slightly allantoid, slightly narrower in apical part, hyaline, thin-walled, smooth, IKI–, CB–, 8.0–8.9(–9.1) × (1.7–)1.8–2.3(–2.6) μm, L = 8.41 μm, W = 2.03 μm, Q = 4.15 (n = 30/1).

Xylodon granulanoides **J.L. Zhang, H.M. Zhou & C.L. Zhao, sp. nov.**

MycoBank No: 856343

Figs 13, 14

Diagnosis. *Xylodon granulanoides* differs from *X. granulans*. by its varied cystidia and broadly ellipsoid, thick-walled basidiospores measuring 4.7–5.3 × 3.6–4.1 µm.

Holotype. China • Yunnan Province, Wenshan, Pingbian County, Wenshan National Nature Reserve, 23°22'N, 103°93'E, evel. 1753 m asl., on fallen angiosperm branch, 28 July 2019, CLZhao 17253 (SWFC).

Etymology. *Granulanoides* (Lat.) refers to the new species' resemblance to *Xylodon granulans*.

Figure 13. Basidiomata of *Xylodon granulanoides* (holotype, CLZhao 17253) **A** the front of the basidiomata **B** characteristic hymenophore. Scale bars: 1 cm (**A**); 1 mm (**B**).

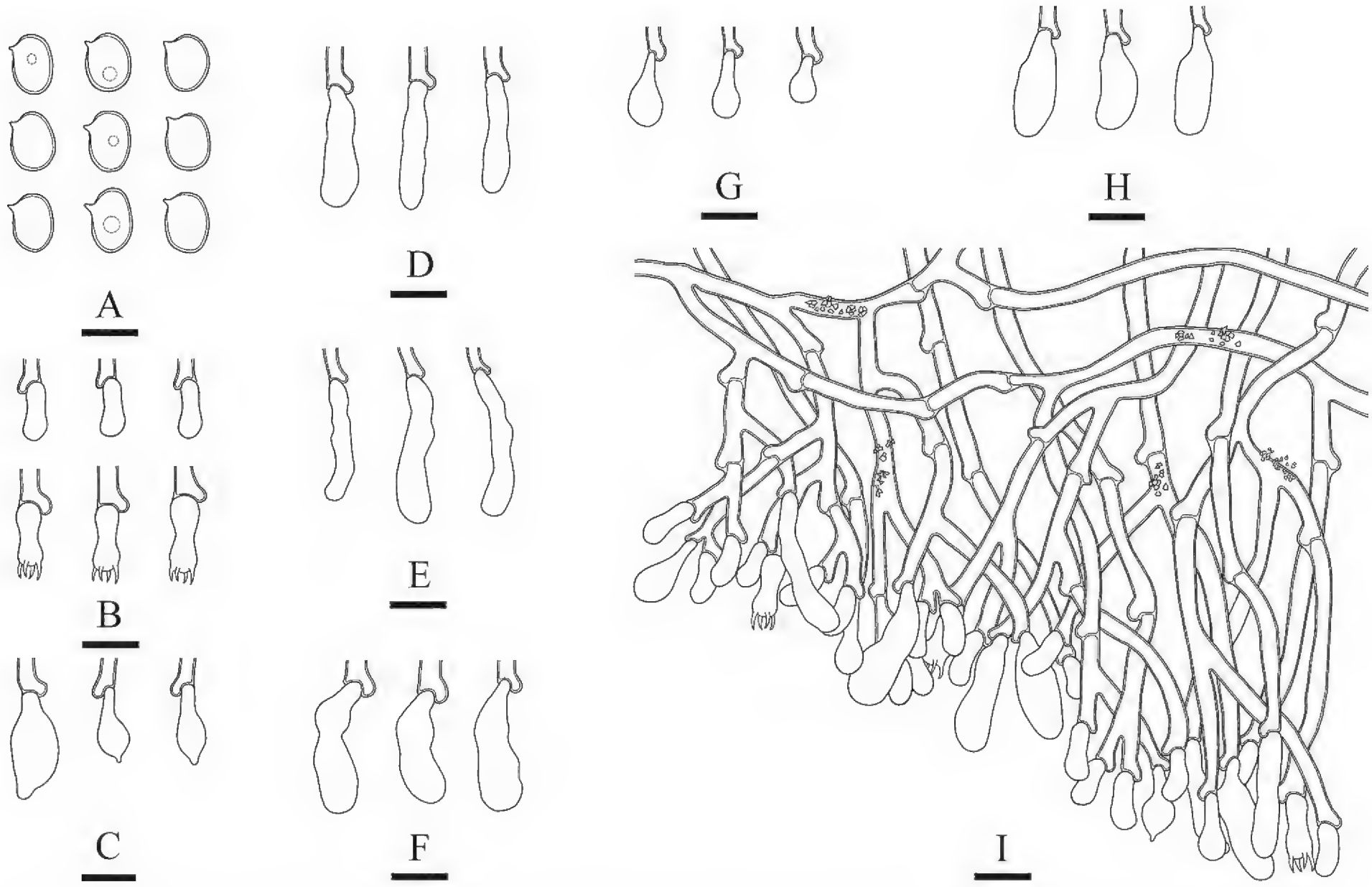

Figure 14. Microscopic structures of *Xylodon granulanoides* (holotype, CLZhao 17253) **A** basidiospores **B** basidia and basidioles **C** cystidioles **D–H** cystidia **I** a section of hymenium. Scale bars: 5 μm (**A**); 10 μm (**B–I**); 10 × 100 oil.

Description. ***Basidiomata*.** Annual, resupinate, adnate, membranous, without odor or taste when fresh, brittle when dry, up to 5.3 cm long, 2.5 cm wide, and 0.1 mm thick. Hymenial surfaces grandinioid, white to cream when fresh, cream to slightly buff upon drying. Sterile margin thin, indistinct, slightly cream, up to 1 mm.

***Hyphal system*.** Monomitic; generative hyphae with clamp connections slightly encrusted with crystals amongst generative hyphae, hyaline, slightly thick-walled, frequently branched, interwoven, 2.5–3.5 μm in diam, IKI–, CB–; tissues unchanged in KOH.

***Hymenium*.** Cystidia numerous, subclavate to cylindrical, or slightly subcapitate, hyaline, thin-walled, 9.5–29.0 × 4.0–9.5 μm; cystidioles are present, subcapitate, hyaline, thin-walled, 13.5–21.0 × 5.0–9.0 μm. Basidia subcylindrical to clavate, hyaline, thin-walled, with four sterigmata and a basal clamp connection, 11.0–16.0 × 4.0–5.5 μm; basidioles dominant, in shape similar to basidia, but slightly smaller. ***Basidiospores*.** Broadly ellipsoid, part has a large drop of oil, hyaline, slightly thick-walled, smooth, IKI–, CB–, (4.6–)4.7–5.3(–5.3) × (3.4–)3.6–4.1(–4.2) μm, L = 4.92 μm, W = 3.90 μm, Q = 1.26 (n = 30/1).

Xylodon granulans **J.L. Zhang, H.M. Zhou & C.L. Zhao, sp. nov.**

MycoBank No: 856344

Figs 15, 16

Diagnosis. *Xylodon granulans* differs from *X. wenshanensis* by its broadly ellipsoid, thin-walled basidiospores measuring 3.8–4.2 × 2.9–3.3 μm.

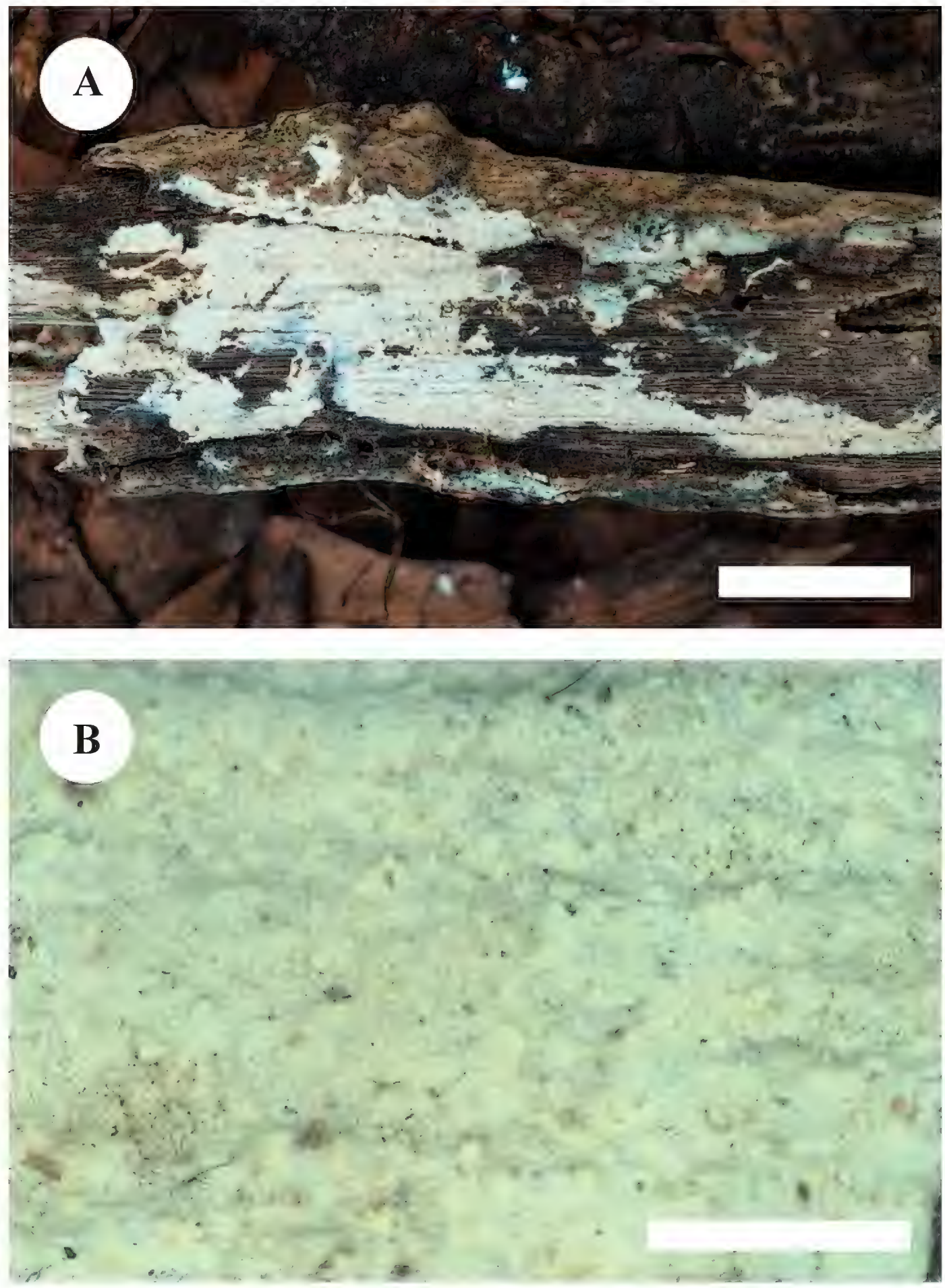

Figure 15. Basidiomata of *Xylodon granulans* (holotype, CLZhao 17866) **A** the front of the basidiomata **B** characteristic hymenophore. Scale bars: 1 cm (**A**); 1 mm (**B**).

Holotype. CHINA • Yunnan Province, Honghe, Pingbian County, Daweishan National Nature Reserve, 28°42'N, 114°11'E, evel. 1356 m asl. on fallen angiosperm branch, 1 August 2019, CLZhao 17866 (SWFC).

Etymology. *Granulans* (Lat.) refers to the granulated hymenial surface.

Description. ***Basidiomata*.** Basidiomata annual, resupinate, adnate, membranous, without odor or taste when fresh, up to 2.4 cm long, 1.3 cm wide, and 50–70 μm thick. Hymenial surface grandinioid, cream when fresh, white to slightly cream when dry. Sterile margin thin, indistinct, slightly cream, up to 1 mm.

***Hyphal system*.** Monomitic; generative hyphae with clamp connections slightly encrusted with crystals amongst generative hyphae, hyaline, slightly

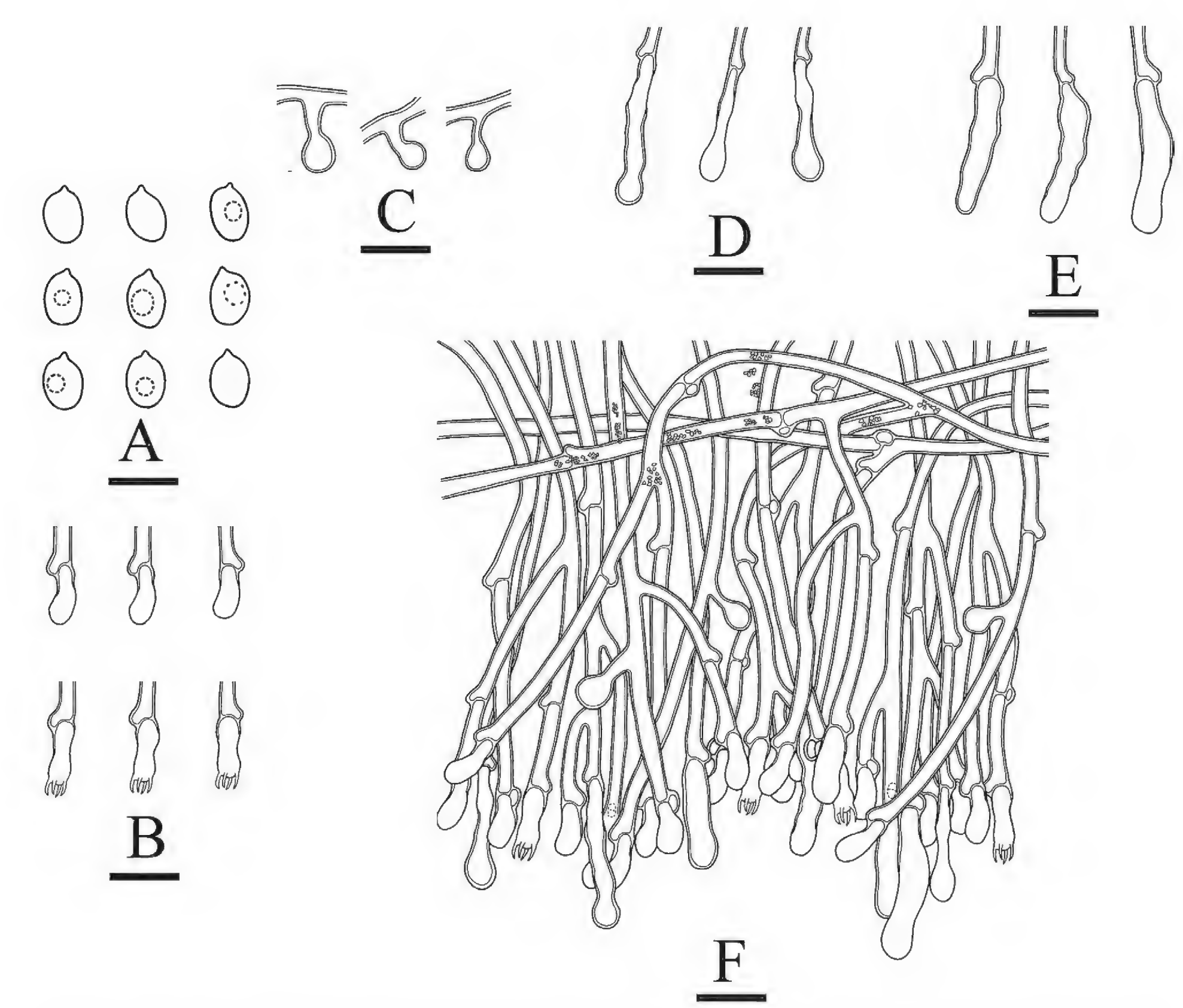

Figure 16. Microscopic structures of *Xylodon granulans* (holotype, CLZhao 17866) **A** basidiospores **B** basidia and basidioles **C–E** cystidia **F** a section of hymenium. Scale bars: 5 μm (**A**); 10 μm (**B–F**); 10 × 100 oil.

thick-walled, frequently branched, interwoven, 2.0–2.5 μm in diam, IKI–, CB–; tissues unchanged in KOH.

***Hymenium*.** Cystidia of two types: (1) Capitate cystidia in hymenium and subiculum, hyaline, slightly thick-walled, smooth, slightly constricted at the neck, with a globose head, 4.5–23.5 × 3.0–4.5 μm; (2) Clavate cystidia, slightly sinuous, hyaline, slightly thick-walled, smooth, 13.0–24.0 × 4.0–5.0 μm. Basidia clavate, slightly sinuous, with four sterigmata and a basal clamp connection, 9.0–12.0 × 3.5–4.5 μm; basidioles dominant, in shape similar to basidia, but slightly smaller. ***Basidiospores*.** Broadly ellipsoid, some of them with an oily drop, hyaline, thin-walled, smooth, IKI–, CB–, (3.7–)3.8–4.2(–4.3) × (2.8–)2.9–3.3(–3.4) μm, L = 4.03 μm, W = 3.12 μm, Q = 1.29–1.29 (n = 60/2).

Other specimen examined. China • Yunnan Province, Honghe, Pingbian County, Daweishan National Nature Reserve, 28°42'N, 114°11'E, evel. 1356 m asl., on fallen angiosperm branch, 1 August 2019, CLZhao 17804 (SWFC).

Discussion

Numerous wood-inhabiting fungal taxa have recently been identified over the last few years (Cui et al. 2019; Guan et al. 2023; Zhao et al. 2023b; Luo et al. 2024; Zhou et al. 2024b). The most recent taxonomic framework recognizes 14 families within Hymenochaetales (Wang et al. 2023; He et al. 2024; Wang and Zhou 2024). To further investigate the wood inhabiting fungal diversity, collections representing five new species *viz*. *Inonotus subglobisporum*, *Kneiffiella bubalina*, *Xylodon granulanoides*, *X. granulans* (Hymenochaetales), and *Botryobasidium daweishanense* (Cantharellales) from Yunnan Province were collected and are introduced based on a combination of morphological features and molecular evidence.

Botryobasidium daweishanense is characterized by an araneose hymenial surface, generative hyphae with clamp connections, subcylindrical basidia (11.5–18.0 × 5.0–8.0 µm), and fusiform, cyanophilous basidiospores (6.1–7.3 × 3.3–3.9 µm). In several previous studies, molecular data have confirmed phylogenetic relationships showing that the genus *Botryobasidium* is nested within the cantharelloid clade and grouped with related genera such as *Cantharellus* Lam., *Clavulina* J. Schröt, *Craterellus* Pers, and *Hydnum* L. (Moncalvo et al. 2006; Bernicchia and Gorjón 2010). Macromorphologically, species of *Botryobasidium* are often mistaken for certain genera, such as *Ceratobasidium* D.P. Rogers, *Sistotrema* Fr., and *Tulasnella* J. Schröt (Donk 1956; Oberwinkler 1982). However, *Botryobasidium* is distinguished from these genera by the absence of epibasidia, sturdy and long sterigmata, and oily inclusions (Kotiranta and Saarenoksa 2005; Gorjón and Hallenberg 2008; Oberwinkler et al. 2017; Zhou et al. 2024c). The phylogram created based on inferences from the ITS+nLSU data in the present study aligns with previous research. According to the phylogram (Fig. 1), the new species of *Botryobasidium daweishanense* was grouped into the genus *Botryobasidium* (Botryobasidiaceae). Phylogenetic analysis of the ITS system (Fig. 2) revealed that the new species *Botryobasidium daweishanense* is grouped with three taxa: *B. intertextum*, *B. leptocystidiatum*, and *B. subcoronatum*. However, morphologically, *Botryobasidium intertextum* differs macroscopically from *B. daweishanense* in being initially thin, hypochnoid, and white and later displaying pellicular and yellowish hymenial surfaces. In contrast, the hymenial surface of *B. daweishanense* is araneose and exhibits a straw-yellow to cream color when dry. In addition, at the micro level, *Botryobasidium intertextum* is distinguishable from *B. daweishanense* by its larger basidiospores (7.0–9.5 × 1.8–2.81 µm) and basidia (15–21 × 5–6.5 µm; Kotiranta and Saarenoksa 1990). *Botryobasidium leptocystidiatum* and *B. daweishanense* both display an arachnoid hymenial surface macroscopically; however, *B. daweishanense* appears cream-colored when fresh and straw-yellow to yellowish when dry, whereas *B. leptocystidiatum* is grayish-white to smoky gray when fresh and grayish-white to ivory when dry. Additionally, microscopically, *B. leptocystidiatum* features tubular cystidia, 6–7 sterigmata, and smaller basidia (10.5–15 × 7–8 µm) and longer basidiospores (6.5–7.8 × 2.9–3.7 µm) than *B. daweishanense* (Zhou et al. 2024c). *Botryobasidium subcoronatum* is distinguished from *B. daweishanense* by the former being thin, floccose to hypochnoid, and whitish at first, followed by having a yellowish to ochraceous hymenial surface. On a microscopic level, the species *Botryobasidium subcoronatum* has relatively larger basidia (20–25 × 7–9 µm) and narrower basidiospores (6–7.5 × 2.5–3 µm; Eriksson and Ryvarden 1973).

Inonotus subglobisporum is characterized by perennial, laterally stipitate basidiomata; tapered, dark brown, thick-walled setae (12.0–69.5 × 4.0–11.0 µm); and subglobose, cyanophilous basidiospores (3.6–4.3 × 2.8–3.5 µm). In the phylogenetic tree of Wu et al. (2022), species of *Inonotus* formed a monophyletic clade; however, *Inonotus* may still be a polyphyletic genus because most species within the genus have not been phylogenetically analysed. Wagner and Fischer also regarded *Inonotus* as a polyphyletic group (Wagner and Fischer 2002; Lin et al. 2023). In the present study, the phylogenetic analysis of the ITS system (Fig. 4) was consistent with previous reports and revealed that the species *Inonotus subglobisporum* was a sister to *I. radiatus*. However, morphologically, the species *Inonotus radiatus* differs from *I. subglobisporum* in terms of its annual basidiomata, which are typically in imbricate clusters; hooked setae; and ellipsoid, hyaline to pale yellowish basidiospores (3.8–5 × 2.6–3.5 µm; Dai 2010).

Kneiffiella bubalina is characterized by cream-colored basidiomata, slightly thick-walled generative hyphae, and cylindrical to slightly allantoid basidiospores (8.0–8.9 × 1.8–2.3 µm). Riebesehl and Langer (2017) showed the monophyly of *Kneiffiella* species by inferring ITS sequences using Bayesian analysis. Wang et al. (2021) classified *Kneiffiella* as belonging to the family Chaetoporellaceae (Riebesehl and Langer 2017; Wang et al. 2021; Langer et al. 2022). Based on a phylogenetic analysis of the ITS + nLSU system (Fig. 3), we determined that the genus *Kneiffiella* is nested in the Chaetoporellaceae clade. Phylogenetic analysis of the ITS system (Fig. 5) revealed that the new species, *Kneiffiella bubalina*, is a sister to *K. subalutacea*. Morphologically, *Kneiffiella subalutacea* resembles *K. bubalina* because of its smooth hymenial surface, tubular, obtuse apical part, and thick-walled cystidia. However, *Kneiffiella subalutacea* can be distinguished from *K. bubalina* by its yellowish basidiomata and allantoid, smooth, thin-walled basidiospores (6–8 × 1.5–2.0 µm; Eriksson and Ryvarden 1976).

Xylodon granulanoides is characterized by grandinioid hymenial surfaces, varied cystidia, and broadly ellipsoid, thick-walled basidiospores (4.7–5.3 × 3.6–4.1 µm). *Xylodon granulans* is characterized by grandinioid hymenial surfaces, capitate cystidia and clavate cystidia, and broadly ellipsoid, thin-walled basidiospores (3.8–4.2 × 2.9–3.3 µm). In several previous phylogenetic studies based on multiple loci in the family Schizoporaceae, three genera, *Fasciodontia* Yurchenko & Riebesehl, *Lyomyces*, and *Xylodon*, were located in this family (Wang et al. 2021; Yuan and Zhao 2024). The present study's phylogram inferred from the ITS+nLSU data (Fig. 3) shows that two new species, *Xylodon granulanoides* and *X. granulans*, are grouped within the family Schizoporaceae. Based on the ITS topology (Fig. 6), these two new species are closely clustered with five other species: *Xylodon bambusinus*, *X. fissuratus*, *X. montanus*, *X. subclavatus*, and *X. wenshanensis*; meanwhile, the taxon *X. granulans* is a sister to *X. granulanoides*. However, morphologically, *Xylodon granulans* differs from *X. granulanoides* in that *X. granulans* lacks cystidioles and exists as broadly ellipsoid, thin-walled basidiospores (3.8–4.2 × 2.9–3.3 µm). *Xylodon bambusinus* differs from *X. granulans* and *X. granulanoides* in its ceraceous basidiomata, fusiform cystidia and capitate cystidia, and broad, ellipsoid, thin-walled basidiospores (4–5.5 × 3–4 µm; Ma and Zhao 2021). *Xylodon fissuratus* and *X. montanus* differ from *X. granulans* and *X. granulanoides* in that *X. fissuratus* and *X. montanus* have only one cystidia. In contrast, *X. fissuratus* has capitate cystidia, a thin-walled hyphal structure, and ellipsoid, thin-walled basidiospores (4.0–5.0 × 3.0–4.0 µm; Guan et al.

2023). *Xylodon montanus* has a smooth hymenial surface, moniliform cystidia, and ellipsoid to broad ellipsoid basidiospores (3.9–5.3 × 3.2–4.3 µm; Qu et al. 2022). *Xylodon subclavatus* can be distinguished from *X. granulans* and *X. granulanoides* by its cracked, aculei wart-like to conical, blunt to acute hymenial surface, and four types of cystidia: subclavate, hyphoid, capitate to sucapitate, and moniliform (Yurchenko et al. 2013). *Xylodon wenshanensis* can be distinguished from *X. granulans* and *X. granulanoides* by its capitate cystidia, clavate cystidia, and ellipsoid, thin-walled basidiospores (3–5 × 2–3.5 µm; Luo et al. 2022).

The families Chaetoporellaceae, Hymenochaetaceae, and Schizoporaceae represent a well-studied group within Hymenochaetales (Luo and Zhao 2021; Langer et al. 2022; Cho et al. 2024; Freire and Soares 2024; Viner et al. 2024); however, the diversity of species in China remains poorly understood, particularly in the southwestern region. Additionally, the genus *Botryobasidium* has rarely been reported in recent years, particularly in southwestern China. Therefore, the species diversity of Cantharellales and Hymenochaetales in China, particularly in the subtropical and tropical regions, has not been sufficiently studied. This study contributes to our understanding of fungal diversity in these areas and underscores the urgent need for further fieldwork and molecular analyses to identify new taxa. Our findings confirm that fungal diversity is abundant in southwestern China.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization, HZ and JZ; methodology, HZ and JZ; software, HZ, JZ, and ZG; validation, HZ and JZ; formal analysis, HZ and JZ; investigation, HZ, CZ, and JZ; resources, HZ; writing—original draft preparation, HZ, JZ, and ZG; writing—review and editing, HZ and JZ; visualization, HZ and JZ; supervision, HZ and JZ; project administration, HZ; funding acquisition, HZ. All authors have read and agreed to the published version of the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text.

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